DAG-TM Concept Element 5
En Route Free Maneuvering

Operational Concept Description

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Prepared for

NASA Ames Research Center
AATT Project Office
Code AT: 262-5
NASA Ames Research Center
Moffett Field, CA 94035-1000

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Preface

This report was developed from the referenced documents available at the time of publication in order to conform to the required contents of an Operational Concept Description (OCD) as jointly defined by National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) Free Flight Project Office. The majority of the descriptive material has been taken directly from the referenced documents. Modifications have been made to add sections not in previous concept descriptions, to improve readability, and to reflect the most currently available information. The authors would like to thank Mssrs. Mark Ballin, David Wing, and Richard Mogford for their patience and help in extracting the necessary information.

This approach to the development of this document was taken in order to remain faithful to the efforts that are presently being undertaken by the NASA AATT Project Office, the Tool Developers and the associated NASA AATT contractors.

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1. Scope

This Distributed Air Ground (DAG) Traffic Management (TM) Concept Element (CE) 5 Operational Concept Description (OCD) is intended to provide sufficient detail to form a basis for further research into the concept. This OCD has a focus on operational and system requirements, and deliberately avoids specific design information to the extent possible. The NASA Langley Research Center is in the process of designing automated airborne systems to test the CE 5 concept, including the Autonomous Operations Planner (AOP) that will function on board free maneuvering aircraft. . NASA Ames Research Center is developing a complementary air traffic control simulation capability, including appropriate decision support tools required for CE 5. The description is consistent with, and provides additional guidance to, these design efforts.

Finally, specifications are omitted from this document, since capabilities to support the DAG-TM CE 5 concept should evolve as a result of the research to be conducted. To avoid confusion with widely discussed tools such as Automatic Dependent Surveillance – Broadcast (ADS-B) or Controller Pilot Data Link Communications (CPDLC) whose specifications are being developed or discussed, this OCD describes the capabilities rather than the systems necessary to support the concept.

1.1 Identification

This document applies to the DAG-TM CE 5 entitled "En Route Free Maneuvering"

1.2 System Overview

Purpose: The purpose of DAG-TM CE 5 is to eliminate excessive and non-preferred trajectory deviations resulting from separation assurance and/or local Traffic Flow Management (TFM) conformance constraints. Another major purpose is to distribute the separation assurance and tactical traffic management functions to the flight deck, greatly adding to the "scalability" of the system. Finally, CE 5 will allow greater user flexibility and autonomy that is consistent with the goals of the industry efforts towards Free Flight (Reference 1).

General Nature of the System: Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local TFM constraints.

History of System Development, Operation, and Maintenance: The DAG-TM concept describes potential modes of operation within the Free Flight concept defined by the RTCA Task Force 3. The goal of DAG-TM is to enhance user flexibility and efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the National Airspace System (NAS).

To explore the DAG-TM concept, the Advanced Air Transportation Technologies (AATT) Project formed a DAG-TM Team that met during 1999 and developed a Concept Definition document (Reference 2). This document defined 15 DAG-TM "concept elements", covering air traffic management (ATM) operations in all phases of flight. The defined phases were:

- Gate-to-Gate (information access and exchange)
- Pre-Flight Planning
- Surface Departure
- Terminal Departure
- En Route
- Terminal Arrival
- Terminal Approach
- Surface Arrival

In 2000, the AATT Project selected an initial set of four concept elements (DAG-TM CEs) to pursue further concept exploration (research) activities.

- CE 5: En Route Free Maneuvering
- CE-6: En Route Trajectory Negotiation
- CE-7: En Route: Collaboration for Mitigating Local TFM Constraints due to Weather, Special Use Airspace (SUA), and Complexity
- CE-11: Terminal Arrival: Self-Spacing for Merging and In-Trail Separation

In May 2000, a DAG-TM workshop was held at the NASA Ames Research Center to explain to industry the AATT Project's activities and plans for the concept. The workshop focus was on the four initial CEs being developed. Under NASA AATT NASA Research Announcement (NRA) Research Task Order (RTO) 41, a contractor team consisting of Titan Systems Corporation (formerly System Resources Corporation) and Seagull Technology prepared detailed descriptions of each of the four selected CEs. This OCD has been developed from the detailed description of objectives and operational concepts for CE 5, En Route Free Maneuvering that was produced as a result of RTO 41 (Reference 3).

Project Sponsor, Acquirer, User, Developer, and Maintenance Organizations: The NASA AATT Project is the sponsor of DAG-TM CE 5. The concept is being co-developed at the NASA Langley and NASA Ames Research Centers.

When implemented, the acquirer, user, and maintenance organization will be the FAA for any ground elements required and the airlines/users for any airborne elements.

Current and Planned Operating Sites: There are no current or planned operating sites. However, the concepts behind CE 5 have applicability throughout the NAS.

Other Relevant Documents: Documents that are relevant to the DAG-TM CE 5 concept are found in Section 2.

1.3 Document Overview

The AATT NAS OCD (in preparation) documents current research and provides concept guidance for all AATT projects. However, it was designed with the understanding that each project element would require a separate detailed description of a subset or domain in the NAS in which a particular deficiency is addressed. This OCD is intended to provide guidance for DAG-TM CE 5 system requirements development, to address how DAG-TM CE 5 fits into the overall NAS, and to provide a means to help transfer this technology to the FAA.

This document is organized according to a format mutually agreed upon by the NASA AATT and FAA Free Flight projects. It is based on the IEEE J-STD-16-1995 standard. Descriptions of the OCD sections follow.

Section 1. Scope: This section contains a full identification of the system to which this OCD applies. It briefly states the purpose of the system; describes the general nature of the system; summarizes the history of system development, operation, and maintenance; identifies the project sponsor, acquirer, user, developer, and maintenance organizations; identifies current and planned operating sites; summarizes the purpose and contents of this document; describes any security or privacy protection considerations associated with its use; and lists other relevant documents.

Section 2. Referenced Documents: This section lists the number, title, version, date, and source of all documents referenced in this OCD.

Section 3. Current System/Situation: This section describes the background, mission, objectives, and scope of the current system/situation including applicable operational policies and constraints and a description of the current system/situation. The description includes, as applicable:

- The operational environment and its characteristics
- Major system components and the interconnections between these components
- Interfaces to external systems or procedures
- Capabilities/functions of the current system
- Charts and accompanying descriptions depicting input, output, data flow, and manual and automated processes
- Performance characteristics, such as speed, throughput, volume, and frequency
- Quality attributes, such as reliability, maintainability, availability, flexibility, portability, usability, and efficiency
- Provisions for safety, security, privacy protection, and continuity of operations in emergencies

In addition, a description of the types of users or personnel involved in the current system is included. This section also provides an overview of the support strategy for the current system.

Section 4. Justification for and Nature of Change: This section describes new or modified aspects of user needs, threats, missions, objectives, environments, interfaces, personnel, or other factors that require a new or modified system. It summarizes deficiencies or limitations in the current system that make it unable to respond to these factors. All new or modified capabilities/functions, processes, interfaces, or other changes needed to respond to these factors are summarized in this section. In addition, this section identifies priorities among the needed changes; changes considered but not included; the rationale for not including them; and, any assumptions and constraints applicable to the identified changes.

Section 5. Concept for a New or Modified System: This section describes the background, mission or objectives, and scope of the new or modified system and any applicable operational policies and constraints and a description of the new or modified system. The description includes, as applicable:

- The operational environment and its characteristics
- Major system components and the interconnections between these components
- Interfaces to external systems or procedures
- Capabilities/functions of the new or modified system
- Charts and accompanying descriptions depicting input, output, data flow, and manual and automated processes
- Performance characteristics, such as speed, throughput, volume, and frequency
- Quality attributes, such as reliability, maintainability, availability, flexibility, portability, usability, and efficiency
- Provisions for safety, security, privacy protection, and continuity of operations in emergencies

In addition, a description of the types of users or personnel involved in the new or modified system is included. This section also provides an overview of the support strategy for the new or modified system.

Section 6. Operational Scenarios: This section describes one or more operational scenarios that illustrate the role of the new or modified system, its interaction with users, its interface to other systems, and all states or modes identified for the system.

Section 7. Summary of Impacts: This section describes anticipated operational, organizational, and development impacts on the user, acquirer, developer, and maintenance organizations.

Section 8. Analysis of the Proposed System: This section provides a qualitative and quantitative summary of the advantages, disadvantages, and/or limitations of the new or modified system. Major system alternatives, the tradeoffs among them, and rationale for the decisions reached are also provided.

Section 9. Notes: This section contains general information that will aid the reader's understanding of this OCD. It includes an alphabetical listing of all acronyms and abbreviations and their meanings as used in this document, and a list of terms and definitions.

Section 10. Annexes: These are used to provide information published separately for convenience in document maintenance. Each annex is referenced in the main body of the OCD where the information would normally have been provided.

2. Referenced Documents

Documents Referred to in This OCD

1. *Government/Industry Operational Concept for the Evolution of Free Flight,* RTCA Incorporated, December 1, 1977.
2. *Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM) Version 1,* AATT Project, September 30, 1999.
3. *Detailed Description for CE 5; En Route Free Maneuvering,* **Charles T. Phillips**, Titan Systems Corporation, October 2000
4. *FAA Order 7210.3S; Facility Operation and Administration*; February 21, 2002
5. *FAA Order 7110.65N,* Air Traffic Control; February 21, 2002.
6. *Research Plan for Distributed Air/Ground Traffic Management (DAG-TM) Version 1.01,* AATT Project, October 6, 1999

Other Relevant Documents

7. *Draft Aircraft Systems and Operations Sub-element 6 Plan V4.0,* AATT Project Office, September, 2002
8. *A Flight Deck Decision Support Tool for Autonomous Airborne Operations,* **Mark G. Ballin, Vivek Sharma, Robert A. Vivona, Edward J. Johnson,** and **Ermin Ramiscal**, AIAA Paper 2002-4554, August 2002.
9. *NASA Langley and NLR Research of Distributed Air/Ground Traffic Management,* **Mark Ballin, Jacco Hoekstra, David Wing,** and **Gary Lohr,** AIAA Paper 2002-5826, August 2002
10. *Use of Traffic Intent Information by Autonomous Aircraft in Constrained Operations,* **David J. Wing, Bryan Barmore,** and **Karthik Krishanamurthy**, AIAA Paper 2002-4555, August 2002.
11. *Distributed Air-Ground Traffic Management for En Route Flight Operations,* **Steven Green** and **Karl Bilimoria**, AIAA Paper 2000-4064, August 2000.
12. *Principals of Operations for the Use of ASAS,* FAA/Eurocontrol Cooperative R&D, June 2001
13. *Application of Airborne Conflict Management: Detection, Prevention, & Resolution,* RTCA SC 186, October 2000.
14. NLR (Netherlands), Overview of NLR Free Flight Project 1997-1999, NLR-CR-2000-227, May 2000.
15. *Airborne Separation Assurance and Traffic Management: Research of Concepts and Technology,* **Ballin, M.G**. et al, AIAA Paper 99-3989, August 1999.
16. *Technical Performance Metrics Description Document for NASA AATT,* Volpe National Transportation Systems Center, November 1, 1999

3. Current System/Situation

3.1 Background, Objectives, and Scope

In today's en route airspace environment, many aircraft must fly non-optimum routes because of deviations from the user-preferred path. These inefficiencies result mainly from either conflict situations with other traffic or from conformance with local TFM constraints. However, often the deviations from the optimum path do not meet user preferences or are excessive. The focus of CE 5, En Route Free Maneuvering, is the investigation of and proposed solution to two of the problems leading to these excessive or non-preferred deviations. As stated in the Concept Definition for DAG-TM (Reference 2):

(a) Air Traffic Service Provider (ATSP) often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current air traffic control (ATC) system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers to allow them to pay less attention to each situation. Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary "resolution" of false alarms (i.e., predicted "conflicts" that would not have materialized had the aircraft continued along their original trajectories). In those cases where a conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and displays), and also to a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b) ATSP often cannot accommodate the user's (flight crew or Airline Operations Center (AOC)) trajectory preferences for conformance with local TFM constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4D trajectory plan while the aircraft is en route. Currently, the user (flight crew or AOC) is required to submit a request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (e.g., airspace congestion, arrival metering/spacing) can result in the flight crew or AOC requesting an unacceptable trajectory. The ATSP is often forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences. Further negotiation between the ATSP and flight crew can adversely impact voice-communication channels and increase workload for both.

3.2 Operational Policies and Constraints

The operational policies and constraints relevant to the present traffic management system are contained in References 4and 5:

- *FAA Order 7210.3S, Facility Operation and Administration*; February 21, 2002; Part 2, Air Route Traffic Control Centers is particularly relevant to this OCD.
- *FAA Order 7110.65N, Air Traffic Control*; February 21, 2002; Chapter 2 – General Control also contains material that describes the operations of the existing air traffic control system.

3.3 Description of Current System or Situation

The following characteristics of the present system cause the user to deviate from a user-preferred path resulting in excessive or unnecessary deviations. These deviations result from: trajectory prediction uncertainty; ATSP workload limitations; and lack of user preference knowledge.

Trajectory Prediction Uncertainty: To solve anticipated air traffic conflict situations, future aircraft trajectories must be predicted. The accuracy of these predictions determines the breadth of resolution options available. If trajectory predictions are inaccurate, resolution options involving legal, but closer separation are unavailable. These limitations in resolution options contribute to deviations from user-preferred trajectories. Instead of a user being able to fly a user-preferred trajectory with small deviations for traffic constraints, the user may have to fly a trajectory with much larger deviations to accommodate the uncertainty of the aircraft's trajectory as well as other traffic trajectories.

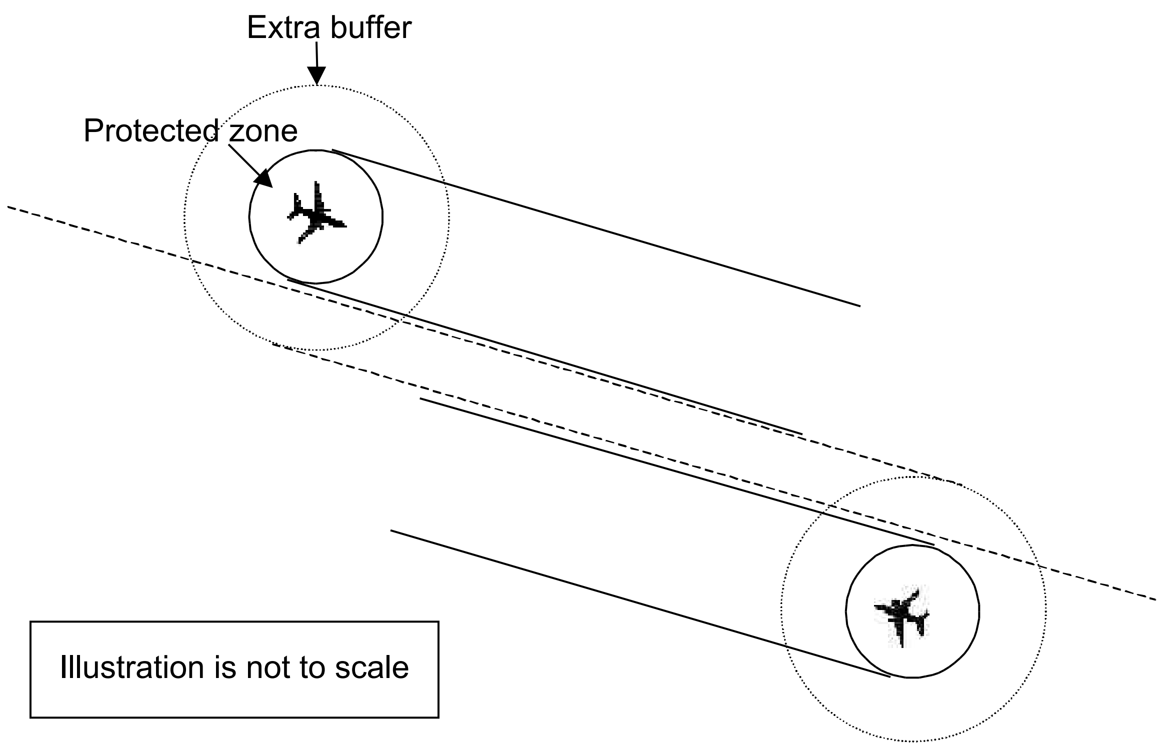
Certain characteristics of current air traffic systems are the cause of trajectory prediction uncertainty. The first is that trajectory adjustments made while en route are based on a sector-oriented viewpoint, as opposed to a whole-trajectory viewpoint. This segregation of a trajectory into sector-defined portions means that trajectory adjustments that will be made in future sectors are difficult to predict.

A second cause of uncertainty is the lack of accurate future information about the air traffic environment. **First**, the actual trajectories followed by aircraft are often not known in the future, because the trajectories will change due to unanticipated conflicts. **Second**, airspace restriction areas due to weather or congestion are not known accurately because of the dynamic nature of these area hazards. **Third**, there is imperfect knowledge of wind fields. **Fourth**, future aircraft intent information is not readily accessible. Within a given sector, a controller can anticipate the resolution maneuvers that will be needed, and, therefore, the intent of the aircraft. However intent information for downstream sectors is not readily accessible, since different controllers are involved in resolutions for these sectors. **Lastly**, future trajectory predictions are not displayed effectively. Currently, the ATSP has access to a tool that shows a projection of an aircraft's predicted path for a short look-ahead time, but not for an entire trajectory.

One effect of trajectory prediction uncertainty is the implementation of larger-than-necessary buffers for protected zones around aircraft for separation assurance. Because the future trajectory is uncertain, extra distance is added to the normal protected zones. This extra uncertainty buffer results in a separation well beyond the protected zones as illustrated in Figure 1.

Also, trajectory prediction uncertainty may cause excessive resolution maneuvers. Resolutions are made to avoid not only normal protected zones, but also extra uncertainty buffers. Although these solutions are robust, they also cause maneuvers that may be larger than necessary for legal separation assurance and further deviate a user from the user-preferred path.

Figure 1. Aircraft Normal Protected Zones and the Effect of Larger Buffer Zones



<u>ATSP Workload Limitations:</u> Currently, the ATSP must provide separation services necessary for an IFR flight's safety. These tasks include trajectory prediction, conflict detection and resolution, local traffic flow constraint conformance, trajectory adjustments, and flight plan conformance monitoring.

The root cause of ATSP workload limitations is that the ATSP has responsibility for multiple aircraft. Therefore, the ATSP often cannot monitor individual aircraft for long periods of time, and may not be able to provide individual aircraft the ability to follow user-preferred trajectories. Furthermore, as more aircraft come under the jurisdiction of the ATSP, each aircraft will have less share of the controller's attention. As traffic density increases, the ability to implement user-preferred trajectories decreases.

One effect of ATSP workload limitations is the imposition of larger-than-necessary buffers for protected zones. Because controllers cannot constantly monitor individual aircraft, a buffer is added to the protected zone so that an aircraft is safe until the ATSP has time to mentally revisit the aircraft. These buffer zones have the same effects as the zones caused by trajectory prediction uncertainty described above, and these zones are additive.

Another effect of ATSP workload limitations is a restriction of potential resolution maneuvers that require more monitoring and interaction with the user. The ATSP may select the most easily defined and implemented resolutions, because other, possibly more user-preferred, resolutions would require more ATSP monitoring to implement. In the tradeoff of accommodation of user-preferred solutions versus ease of solution implementation, the ATSP must often choose ease of implementation because of workload constraints. In addition, to formulate these in-flight user-preferred resolutions would require more interactions with the user to attain the user preferences. This increased interaction is not possible, since the ATSP also has responsibility for many other aircraft.

Lack of User-Preference Knowledge for Resolutions: Flight plans are filed at the beginning of a flight, and often must be changed en route because of conflict situations or adherence to local traffic flow constraints. En route adjustments to a flight's trajectory are often made without knowledge of user preferences.

The ATSP often must make trajectory adjustments without knowledge of user preferences because no tools facilitate the transfer of this information and the information is difficult to define in a way easily communicated between the flight deck and the ATSP.

The lack of user-preference knowledge means that the ATSP does not take into account this knowledge when creating solutions to traffic problems. Therefore, trajectory changes due to resolution maneuvers may deviate excessively from the user preference, even though a user-preferred resolution exists that solves the traffic problem.

Lack of Scalability: Many control sectors in the NAS are handling traffic near their maximum capacity. Traditional methods to overcome bottleneck sectors have included splitting sectors into smaller geographic areas so that additional controllers can handle the overload. This method of capacity enhancement is rapidly reaching the limits of its effectiveness, as smaller sectors mean increased intersector coordination, less efficient sector operations due to compressed times in the sector, and of course, additional sectors mean additional controllers.

3.4 Users or Involved Personnel

In this section, the focus is on the roles and responsibilities of the active participants in the present environment or situation. Subsections address the roles and responsibilities of the ATSP, the pilot, and the AOC respectively.

ATSP Roles and Responsibilities: The air traffic controller sends the following four types of messages to aircraft:

- Clearance. This is a required maneuver for separation or traffic management (e.g., move to new altitude, new heading).
- ATC instruction. Similar to a clearance but more urgent (e.g., "go around", "turn left to [new heading]").

- Advisory. Provides a flight crew with awareness of traffic, weather, turbulence, etc.
- Traffic management directive. Informs flight crew of restricted airspace or Required Time of Arrival (RTA) assignment.

Pilot Roles and Responsibilities: The IFR aircraft pilot has responsibility for situation awareness, flight planning/replanning and execution, and adherence to clearances/instructions issued by the ATSP.

AOC Roles and Responsibilities: The AOC dispatcher has the responsibility for scheduling company aircraft and for filing flight plans and amendments that are cooperatively developed with the pilot of the aircraft in question.

Table 1 identifies all potential users or involved personnel, based upon current operations. The list of ATSP personnel was taken from *FAA Order 7110.65N,* Air Traffic Control (Reference 5). Since CE 5 deals primarily with en route and transition operations, only those ATSP positions relevant to those operations are checked. Also, because CE 5 deals with separation assurance and traffic control, only active control positions are indicated, even though all of the other non-control positions play a role in air traffic operations.

Table 1. Users or Involved Personnel in Current Operations

Users or Involved Personnel	Current Operations
Traffic Management Specialist at ATSCSS	
Air Traffic Control Supervisor (ATCS)	
Supervisory Traffic Management Coordinator-in-Charge (STMCIC)	
Operations Supervisors (OS)	
Traffic Management Coordinator (TMC)	
En Route Radar Position – R controller	✓
En Route Radar Associate (RA) – D controller	✓
En Route Radar Coordinator (RC)	
En Route Radar Flight Data (FD) Position	
En Route Non Radar (NR) Position	
Terminal Radar Position – R controller	✓
Terminal Radar Associate (RA) – D controller	✓
Terminal Radar Coordinator (RC)	
Terminal Radar Flight Data (FD) Position	
Terminal Non Radar (NR) Position	
Tower Local Controller (LC)	
Tower Ground Controller (GC)	
Tower Associate	
Tower Coordinator	
Tower Flight Data Position	
Tower Clearance Delivery Position	
Flight Service Station Specialist (FSSS)	
Airline or Aircraft Flight Operations Center (AOC)	✓
Pilot or Flight Crew (FC)	✓

3.5 Support Strategy

To be determined

4. Justification for and Nature of Change

4.1 Justification for Change

The justification for change from the system as it operates today consists primarily of the potential benefits that can be realized by DAG-TM CE 5. The following is a list of the potential benefit mechanisms from en route free maneuvering:

- Distributed decision-making authority may be the key enabler in multiplying the capacity of the NAS by minimizing the occurrence of human workload bottlenecks. It offers the potential of a linearly scalable system that accommodates an increase in demand through a proportional increase in infrastructure and human decision-making capability, whereby each additional aircraft contributes actively to the traffic management solutions. In the future system, free maneuvering aircraft[1] entering the airspace do not need to be managed by the ATSP.
- System-wide reliability and safety improvements may also result from the increased redundancy of traffic management capability.
- Increased user flexibility: The ability to free maneuver increases the number of available and viable solution options to traffic problems.
- Reduction in excessive and non-preferred deviations: Since free maneuvering users can constantly monitor their own trajectories, these trajectories can be more tailored to user preferences.
- Reduction in buffers: Since a free maneuvering user makes his/her own separation decision by looking down his/her aircraft's trajectory, as opposed to a central controller looking at all the trajectories, buffers can be reduced.
- An ATM system based on air-ground distributed control lowers user costs: Because users are in control of their own trajectories, these trajectories can be more optimized to the user-preferred path. If the user-preferred path is based on flight economics, free maneuvering should lower user operating costs, offsetting capital investment costs.
- Reduced ATSP workload: Because many aircraft will have self-separation capability under free maneuvering, the ATSP can focus more on aircraft that do not have self-separation capability. Therefore, the curve of workload as a function of traffic density will be below that experienced by today's ATC system.
- Increased predictability of RTA conformance: Free maneuvering aircraft have better tools for achieving an RTA, since they can use trajectory orientation to anticipate conflicts well ahead and have a better chance to recalculate conflict-free trajectories that will meet the RTA.
- Increased system safety: Because users need surveillance information for free maneuvering, both users and ATSP have traffic situation awareness. This two-pronged approach provides redundancy in separation assurance.

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[1] In this document, free maneuvering and autonomous are used synonymously

· Increased global interoperability: Aircraft equipped for free maneuvering can operate in oceanic and international airspace assuming harmonized ATC support.

4.2 Description of Needed Changes

The solution of allowing more airborne authority and free maneuvering addresses all of the problems identified in Section 3.

Free Maneuvering Addresses Trajectory Prediction Uncertainty: One of the causes of trajectory prediction uncertainty is that, once en route, trajectories are viewed in sector-based portions. Under free maneuvering, the flight crew has a trajectory orientation for its own planning and is not restricted by a controller's sector orientation as today. This results in less disruption of the planned trajectory, leading to improved prediction.

Another cause of trajectory prediction uncertainty is the lack of accurate information about the future air traffic environment. Under free maneuvering, the flight crew has the information and tools to take a long look ahead on the trajectory to see developing weather and congestion and toward potential conflicts with other aircraft, taking into account their intent, and to calculate required maneuvers as early as possible. These activities will reduce uncertainty.

Free Maneuvering Addresses ATSP Workload Limitations: The root cause of ATSP workload limitations affecting user preferences is that the ATSP must take responsibility for multiple aircraft. Each flight crew of a free maneuvering aircraft has authority for its own trajectory. Therefore, flight crews have the option of following user-preferred routes that were impossible before because the ATSP could not devote enough supervision time to a single aircraft.

Free Maneuvering Addresses Lack of User Preference Knowledge for Resolutions: The root cause of lack of user preference knowledge is that the ATSP does not have ready access to the user-preferred knowledge from the flight deck. The free maneuvering aircraft has the ability to respond to many new and unexpected situations during the flight in accordance with preferences.

4.3 Priorities Among the Changes

The basic change that results from DAG-TM CE 5 is to allow appropriately equipped aircraft to accept the responsibility for maintaining separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to active local TFM constraints. As such, priorities among the changes is not applicable in this OCD.

4.4 Changes Considered But Not Included

A major change that was considered but not included in this concept is that of negotiating trajectories between the flight crew and the ATSP rather than permitting free maneuvering aircraft. This alternative is considered in a separate OCD for the DAG-TM CE 6 En Route Trajectory Negotiation and is described in detail in that OCD. No other solutions to this problem were considered.

4.5 Assumptions and Constraints

This section describes the assumptions behind development of the concept description for En Route Free Maneuvering, the current and future conditions under which this concept will be applied, the baseline ATC situation and what changes may have to occur to support this concept, and different environments in which the problem and solution may take different forms. The section has four subsections as follows:

- Airspace Structure and Constraints
- Traffic Mix and Equipage
- Communication, Navigation, and Surveillance (CNS) Infrastructure
- ATM Environment

Airspace Structure and Constraints: En route free maneuvering is designed for domestic en route airspace, although many aspects of the concept element could apply to low-density terminal departure and arrival domains, as well as oceanic and international airspace. CE 5 operation is assumed extend to the terminal arrival metering fix for high density arrivals, and possibly to the initial approach fix or beyond for low density arrivals.

It will need to operate in unconstrained, constrained, and transition airspace. In unconstrained airspace free maneuvering aircraft need make no trajectory adjustments away from user-preferred trajectories except for separation assurance. Constrained airspace includes the following kinds of constraints on user trajectories:

- TFM initiatives (traffic volume restrictions, flow rate assignments)
- Area hazards (weather, SUA)

Transition airspace is that portion of en route airspace immediately outside terminal airspace, within which arriving aircraft are conducting significant descents to their arrival routes and departing aircraft are conducting significant climbs to cruise.

The CE 5 concept does not address strategic traffic management and negotiations concerning constrained airspace, which is the subject of CE 7.

It is assumed that a route structure may exist in the CE 5 environment, along with a system of named waypoints. The latter are used for easy communication of locations. However, free maneuvering aircraft are no longer required to follow these routes. These aircraft may also perform cruise climbs and need not adhere to cardinal altitude rules.

Research will determine a set of feasible procedures for ATC to manage “managed” aircraft, including the use of cardinal altitudes and fixed vs. non-structured routes. Research will determine if there are reasons why structured routing is required for concept feasibility. The end-state assumption is that the managed aircraft can file “direct”, but they may or may not get it depending on the answer to this research issue. The same goes for cardinal altitudes vs. cruise climb.

The concept of “managed only” airspace may be brought into CE 5. In this airspace, aircraft may only operate if they are managed.

Traffic Mix and Equipage: There are two types of aircraft: free maneuvering (aka autonomous) and managed. Free maneuvering aircraft have automation enabling situation awareness, self-separation, and trajectory re-planning and constraint conformance (e.g., flow constraints, SUA constraints). These aircraft have the authority to make trajectory changes with the restriction that no new conflicts be created by their maneuvers within a defined period of time. The appropriate time horizon is a subject of research; initial simulation experiments have used 5 minutes as a starting point. Aircraft must transmit their position and intent to enable conflict detection and resolution by other free maneuvering aircraft and the ATSP.

Free maneuvering aircraft voluntarily equip themselves for self-separation and trajectory re-planning and, by doing so, achieve the benefits while assuming additional responsibilities. A range of capabilities will be permissible. However, there will be a minimum equipment set required to operate autonomously; additional equipage will have to bring additional benefits in order to make the business case for such equipage. Required equipage includes:

- Flight management system
- Datalink
- Interactive, multifunctional cockpit display
- Automatic Dependent Surveillance – Broadcast
- Decision support
- Conflict detection and resolution (CD&R)
- Trajectory re-planning
- Constraint conformance (e.g., meet RTA, avoid SUA)

All types of aircraft (e.g., air carrier, general aviation, corporate, and military) may be free maneuvering. The concept allows, but does not require, association with an AOC. Global interoperability will be a design goal for the free maneuvering aircraft capability.

Managed aircraft continue to be controlled by ATC in a manner similar to today. The concept of managed aircraft equipage is still evolving. In addition to the requirements for today's en route airspace, managed aircraft of the future may choose to obtain some of the equipage that will be required for free maneuvering aircraft, in order to achieve benefits such as increased situation awareness and improved data communications.

CNS Infrastructure: **Communication**: Datalink is the principal addition to today's communications infrastructure. There are two kinds of ground to air datalinks: addressed, for specific constraints, and broadcast, for messages of general interest. Addressed datalink messages to free maneuvering aircraft include controller advisories and traffic management directives for the aircraft, such as commitment to an RTA. Broadcast messages include traffic, weather, and SUA advisories. Air to ground datalink will be used for pilot acknowledgements.

Navigation: The Global Positioning System (GPS) is certified for en route navigation. For automatic dependent surveillance to operate effectively, a free maneuvering aircraft must know its own state with significant accuracy including its position that is obtained by reading from a GPS receiver (or any other navigation system certified to perform to the Required Navigation Performance (RNP)). This state (including position and velocity) and the aircraft's intent must be broadcast regularly via datalink.

Surveillance: Automatic Dependent Surveillance – Broadcast provides autonomous aircraft and the ATSP with surveillance data about autonomous and suitably equipped (e.g., ADS-B equipped) managed aircraft. Conventional (e.g., Mode S) secondary surveillance radars (SSRs) will provide surveillance information to the ATSP on all aircraft, both managed and autonomous. This SSR data will be broadcast via Traffic Information Services – Broadcast (TIS-B) to all autonomous aircraft so they can have situational awareness of all aircraft in their vicinity. This surveillance information on managed aircraft will probably be a subset of the information gathered on autonomous aircraft and will be transmitted less frequently (e.g., every 4 seconds).

ATM Environment: An advanced decision support system, operating in conjunction with the controller display, is essential for the controller to anticipate conflicts far ahead and to implement conflict-free resolutions as required. For the controller to have the most current aircraft intent information as part of decision support, the ATSP automation must have a data fusion capability which includes radar, current flight plan, and aircraft state and intent information from aircraft broadcast.

The CE 5 concept does not require any change in strategic traffic management, although changes as a result of CE 5 may be beneficial. Further research is needed to demonstrate whether changes in local traffic management, either in automation or procedures or both, are required or beneficial.

5. Concept for a New or Modified System

5.1 Background, Objectives, and Scope

As stated in the Concept Definition for DAG-TM CE 5 (Reference 2):

Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local TFM constraints.

Free maneuvering aircraft are those that: (1) are appropriately equipped; (2) have a flight crew that is trained and proficient to operate autonomously; (3) have responsibility for self-separation; and (4) have been granted the authority, and have the capability to use user-preferred trajectory changes without requesting ATSP clearance to do so. Along with this authority, the flight crew takes on the responsibility to ensure that any trajectory change does not generate near-term conflicts with other aircraft in the vicinity. Free maneuvering aircraft continue to follow defined air traffic rules and procedures as is true of all aircraft.

Free maneuvering will allow aircraft to fly more optimized user-preferred trajectories. Under the CE 5 concept, which takes place in the en route operational domain, flight crews have the authority, tools, and infrastructure necessary to provide their own solutions to traffic conflicts and localized TFM constraints imposed by the ATSP. Such constraints will continue to occur throughout en route airspace; examples are en route metering, and RTA in transition.

A user-preferred trajectory modification may be generated by the flight crew, or if time permits, it may be created by the AOC and transmitted to the flight crew via datalink. The flight crew instructs the aircraft's flight management system (FMS) to initiate the trajectory, and at the same time on-board automation broadcasts the modified trajectory using automatic dependent surveillance broadcast to the ATSP and to other aircraft.

5.2 Operational Policies and Constraints

The operational policies and constraints relevant to the present traffic management system are contained in References 4and 5.

- *FAA Order 7210.3S, Facility Operation and Administration*; February 21, 2002; Part 2, Air Route Traffic Control Centers is particularly relevant to this OCD.
- *FAA Order 7110.65N, Air Traffic Control*; February 21, 2002; Chapter 2 – General Control also contains material that describes the operations of the existing air traffic control system.

These operational policies and constraints will have to be modified to accommodate the modes of CE 5 operation that are described in the following paragraphs. Specifically, the modes of operation that require modification to existing operational policies and constraints are:

<u>Operational Processes:</u> The following major operational processes for DAG-TM CE 5 have been identified:

- Flight Crew
  - _ User-Preferred Flight Plan/Trajectory Change
  - _ Traffic Conflicts
  - _ Area Hazard Conflicts
  - _ Meet RTA
- ATSP
  - _ Traffic Conflicts
  - _ Monitor Free Maneuvering Aircraft and Issue Advisories
  - _ Issue Traffic Management Directives
- Flight Crew/ATSP
  - _ Transition of Aircraft Between Free Maneuvering and Managed States

Two of these are discussed below as examples: User-Preferred Flight Plan/Trajectory Change and Area Hazard Conflicts. In the discussion, an aircraft is assumed to be free maneuvering unless otherwise indicated.

Flight Crew: User-Preferred Flight Plan/Trajectory Change

Figure 2 shows the operational sequence diagram for this process. Changing conditions lead the flight crew to question whether the current flight plan/trajectory remains satisfactory. The flight crew evaluates this with the aid of a decision support tool, taking into account user preferences and NAS state information such as traffic management, weather, winds and pilot reports. If the current flight plan/trajectory is still deemed satisfactory in the sense that there is not sufficient benefit to changing it, the process ends. Otherwise, alternative trial trajectories are created by the decision support tool, with reliance on NAS state information. The flight plan of record for this flight may or may not be changed by this alternative. This depends on the flight plan detail and the extent of the changed trajectory. If it would be altered, the flight crew files a flight plan amendment with the ATSP, then activates the new trajectory. Otherwise, the flight crew proceeds immediately to activate the new trajectory. Note that the new trajectory will diverge at some point from the current trajectory. The divergence may be immediate, or it may not occur until considerably later in the future. The aircraft's automatic dependent surveillance broadcasts will quickly inform other aircraft and the ATSP of the new trajectory.

Flight Crew: Area Hazard Conflicts

Figure 3 shows the operational sequence diagram for this process. The aircraft's CD&R decision support tool periodically or continuously checks the aircraft's trajectory for area hazards such as weather fronts or active SUAs, using the most current NAS state information. If a hazard is detected, the decision support tool generates alternative trial trajectories which will be conflict-free. The flight crew evaluates these with the aid of the tool and taking account of user preferences. Out of these alternatives the flight crew chooses the one that is best in their judgment.

As in the previous case, the new trajectory may or may not be so different from the current one that a flight plan amendment needs to be filed. In either case, the flight crew activates the new trajectory and this is quickly broadcast to other aircraft and to the ATSP.

Figure 2. Operational Sequence Diagram for Flight Crew: Flight Plan/Trajectory Change

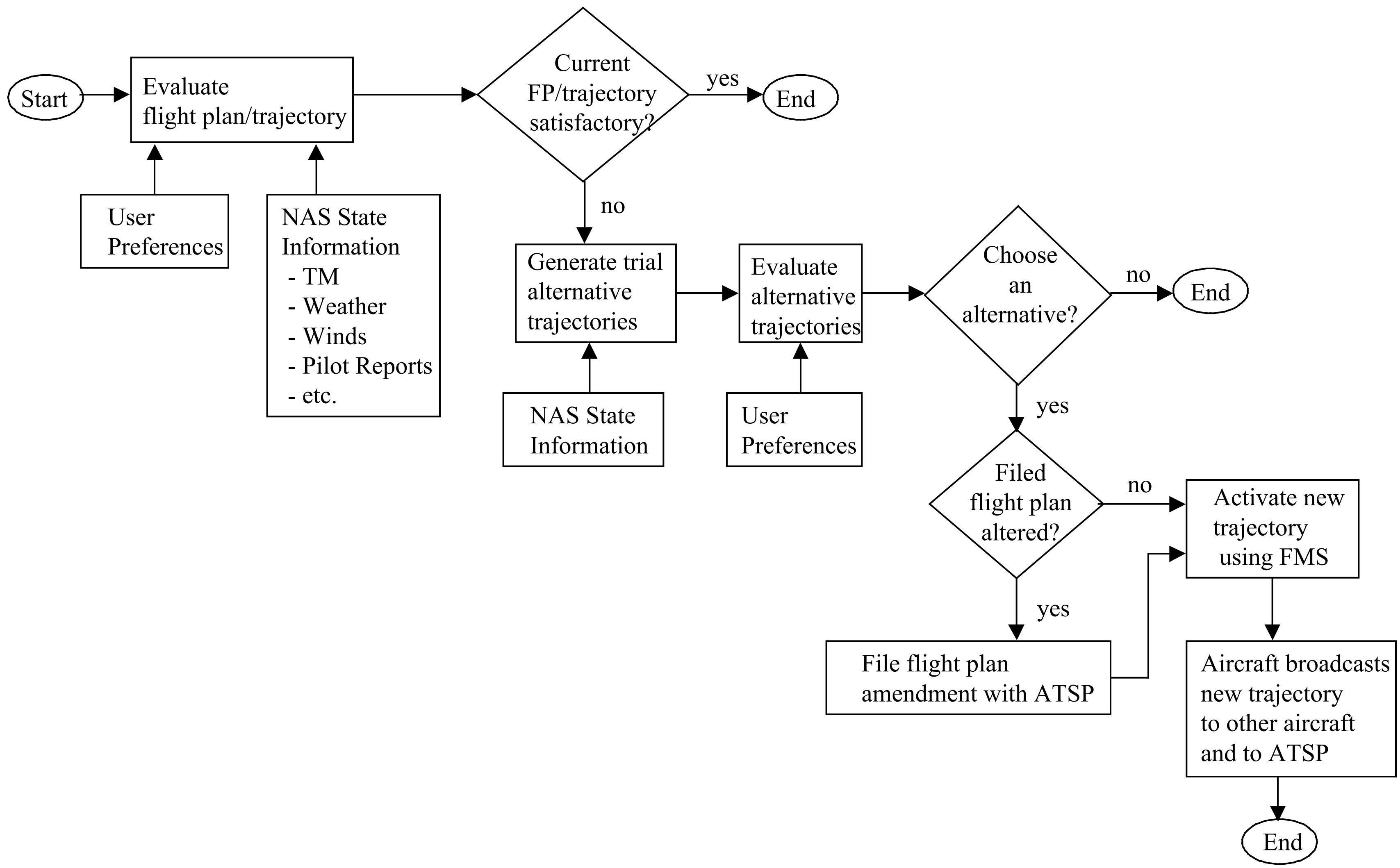
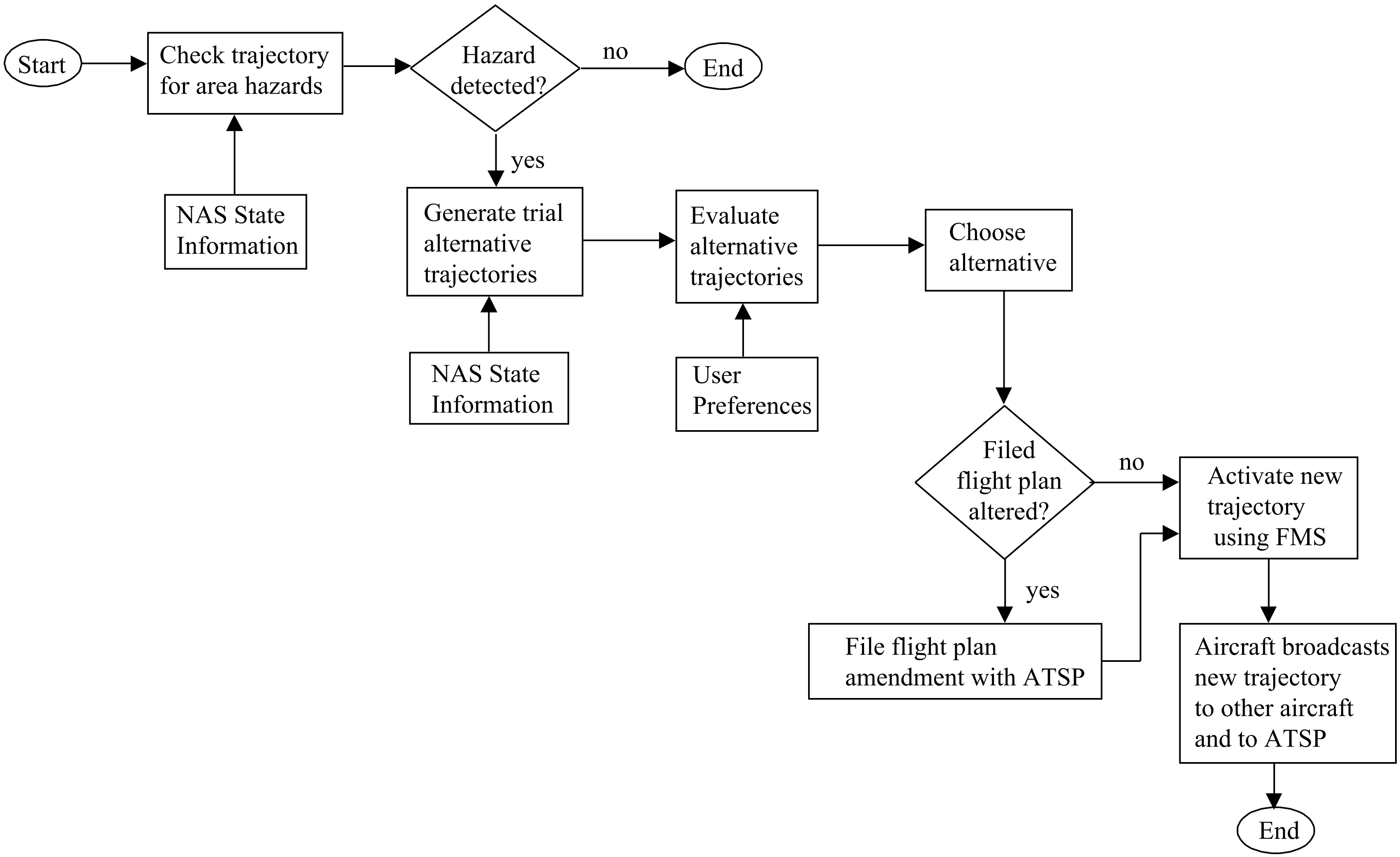


Figure 3. Operational Sequence Diagram for Flight Crew: Area Hazard Conflicts



5.3 Description of the New or Modified System

Overview: In order to implement free maneuvering, several system capabilities are necessary. First, information exchange among all actors must be expanded. CE 5 relies on DAG-TM CE 0, Information Access/Exchange for Enhanced Decision Support, to define the required information. For the autonomous aircraft flight deck situation awareness, this includes:

- State and intent information about other aircraft
- Current and predicted NAS constraint information (delays, flow initiatives, SUA status)
- 4D weather information (winds, temperature, turbulence, storm cells, icing, etc.)
- Real-time pilot reports from aircraft maneuvering near weather-impacted areas

This information comes directly from the ground infrastructure or from other aircraft.

Second, new automation is necessary for both the flight deck and ATC. The flight deck needs automation to process the incoming information for situation awareness, and to assist in the creation of valid, optimized trajectories based on that incoming information. ATC automation also needs to be enhanced for situation awareness, including awareness of free maneuvering aircraft.

Third, the roles and responsibilities of flight crews and the ATSP must be established. Currently defined roles are illustrated in Table 2 (roles in separation assurance) and Table 3 (roles in traffic management). Today, trajectory change authority resides only with the ATSP. In the free maneuvering concept, either the flight crew or the ATSP may have authority, depending on the situation. Also, free maneuvering aircraft must be integrated with managed aircraft. The capability for this meshing of ground and airborne traffic management must be achieved for free maneuvering to be successful.

The controller role changes significantly under the CE 5 concept. The controller retains responsibility for all aircraft that are not free maneuvering. The controller uses CD&R decision support tools to assure separation for managed aircraft, and also to monitor the activities of all aircraft. In the case of a potential conflict between a managed and a free maneuvering aircraft, procedures and flight rules are followed by the free maneuvering aircraft and the controller acting on behalf of the managed aircraft. The traffic management coordinator (TMC) continues to set localized TFM constraints as today. Potential changes in the TMC role are a subject for research.

In order to eliminate the “shared” responsibility between air and ground, free maneuvering aircraft will be given priority over managed aircraft, and the resolution of such conflicts will be accomplished by moving the managed aircraft, clearly the responsibility of the ATSP. This priority status for the autonomous aircraft may also provide an incentive for aircraft to equip for free maneuvering capability.

Figure 4 illustrates this shared concept. This diagram applies to conflicts of a free maneuvering aircraft with other aircraft. The farther away a conflict is detected, the greater the flexibility will be in planning a resolution. As the time before conflict decreases, the certainty of the conflict increases while operational flexibility decreases.

Table 2. Pilot and ATSP Roles in Separation Assurance

Conflict Between	Pilot Role	ATSP Role
Autonomous - Autonomous	Autonomous 1: Use on-board system CD&R, maneuver in accordance with rules to avoid loss in separation. Autonomous 2: Use on-board system CD&R; maneuver in accordance with rules to avoid loss in separation	None
Autonomous – Managed	Autonomous: ATSP will resolve conflict by moving managed aircraft. Do not maneuver to create a new conflict. At some minimum range to a managed aircraft, if ATSP has not provided separation, autonomous aircraft will maneuver to avoid loss in separation. Managed: Respond to ATSP CD&R	Provide separation assurance to managed and autonomous aircraft. Provide traffic advisories to autonomous aircraft about nearby managed aircraft.
Managed - Managed	Managed 1: Respond to ATSP CD&R Managed 2: Respond to ATSP CD&R	Provide separation assurance to managed aircraft.

Table 3. Pilot and ATSP Roles in Traffic Management

Player	Pilot Role	ATSP Role
Autonomous Aircraft	Determine and execute optimal flight path control Inform ATSP and other autonomous aircraft of revised flight plans	Provide TFM Constraints, SUA status, weather, flow initiatives
Managed Aircraft	Follow ATSP clearances	Provide clearances

Figure 4. Temporal Zones for Autonomous Aircraft Separation Assurance

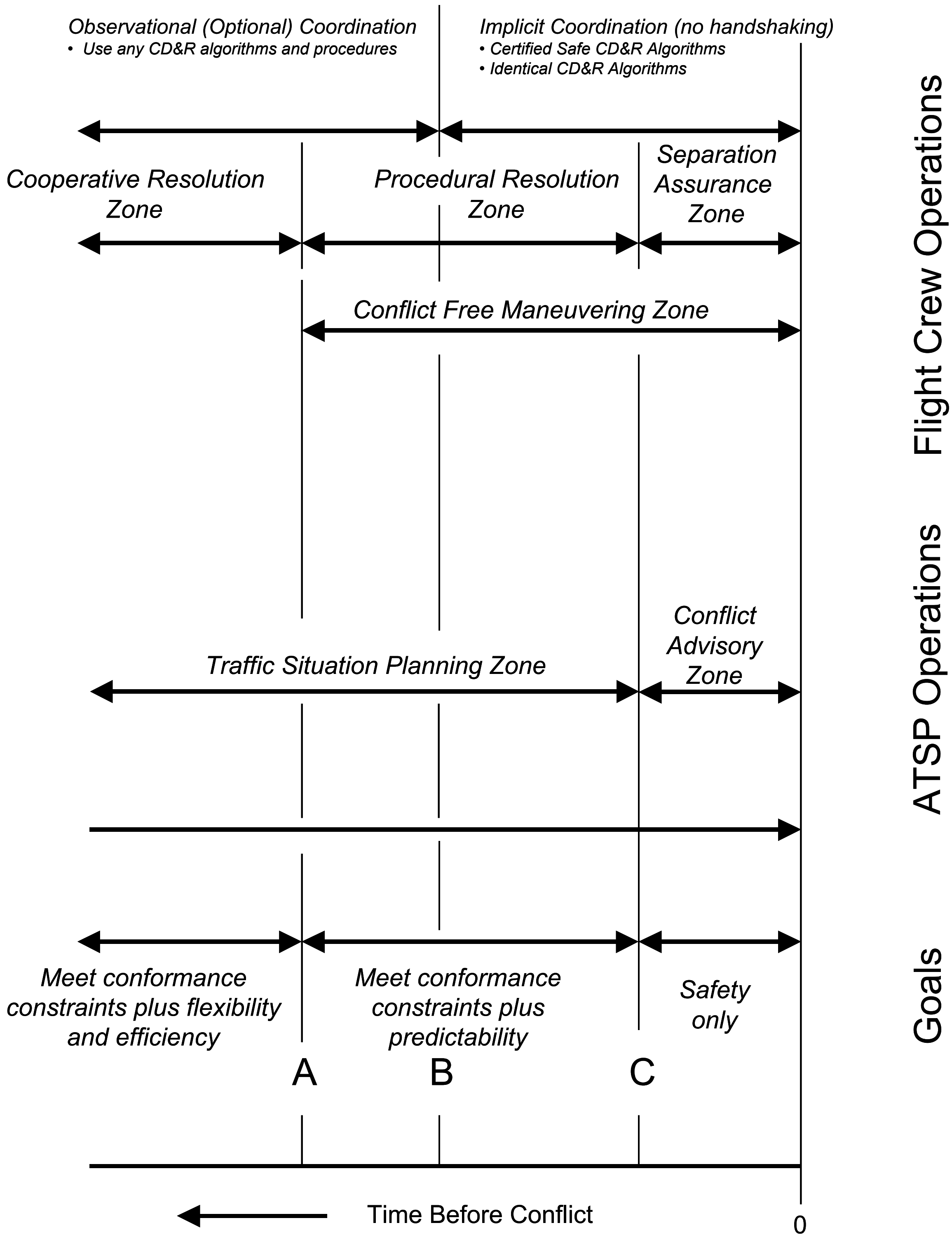


Figure 4 examines separation assurance from both the flight crew and the controller perspective. For the flight crew, the time beyond an outer limit (Time “A”, to be determined by research) is a **cooperative resolution zone**. In this zone coordination can occur, although it is not required, between two aircraft predicted to be in conflict. It is the region of maximum flexibility for a user. Whether or not direct coordination occurs is the option of the user (e.g., airline business decision).[2] Within the same time frame, controllers maintain awareness of traffic and may provide free maneuvering aircraft with advisories to avoid regions of traffic complexity or bad weather.

If the conflict has not been resolved in the cooperative resolution zone, the aircraft enter a **procedural resolution zone** (“A” to “C” minutes before conflict). In this zone there is no negotiation; flight rules are established to provide procedural predictability in conflict resolution and must be followed. Furthermore, when time-to-conflict decreases below ”B” minutes, resolution strategies must be coordinated implicitly. In implicit coordination, if the conflict is between two free maneuvering aircraft, they must use the same certified safe CD&R algorithm. This algorithm must turn both aircraft away from each other, allowing for the cases where either or both aircraft conduct a resolution maneuver. Both aircraft state and intent information may be used in the algorithm. If the conflict is between a free maneuvering aircraft and a managed aircraft, a flight rule first needs to apply. In the CE 5 concept, the free maneuvering aircraft has the right-of-way and the controller should turn the managed aircraft to avoid conflict. In this zone, the controller continues to monitor the actions of free maneuvering aircraft and maneuvers managed aircraft as necessary.

If the time to conflict becomes less than “C” minutes, the free maneuvering aircraft is in the **separation assurance zone** and maneuvers with the primary goal being separation assurance at the expense of all other goals except safety of flight. For the controller this same zone is called the **conflict advisory zone**. In this zone, the controller may issue a conflict advisory to the autonomous aircraft, as a potential backup to a failure of the CD&R on board the autonomous aircraft.

In current airborne research, “A” is 5 minutes, “B” is either 5 minutes or 2 minutes (depending upon the right of way rules being used), and “C” is equal to 2 minutes. Research will further explore and validate/adjust these time horizon values.

The controller continues to direct managed aircraft away from conflicts. The controller role in conflicts between free maneuvering aircraft within the conflict advisory zone is a subject for research and further development of the CE 5 ground concept. This is part of the broader issue of a clear separation of responsibility between the controller and the pilots of free maneuvering aircraft. A fourth zone not shown in the diagram is the **Threat and Collision Avoidance System (TCAS) zone**. We may assume that all free maneuvering aircraft are equipped with TCAS, which commands a resolution to a conflict occurring in less than about 30 seconds.

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[2] Voice communication between aircraft is not considered to be the appropriate coordination mechanism in this zone, or at any other time.

There are a number of assumptions that follow from the distributed responsibility concept. First, controllers' interaction with free maneuvering aircraft consists of advisories and traffic management directives, such as the need to meet an RTA or to avoid areas of traffic saturation. Second, a free maneuvering aircraft may make trajectory changes without restriction, with the exception that it shall not make a maneuver that creates a new conflict with any aircraft (free maneuvering or managed) within "A" minutes away. This is shown in Figure 4 as the **Conflict Free Maneuvering Zone.**

Third, free maneuvering aircraft need automatic dependent surveillance broadcasts from other free maneuvering aircraft for adequate situation awareness. These broadcasts should include (at a minimum) state and preferably intent and occur at a frequency of about 1 per second.

Fourth, to complete situation awareness, free maneuvering aircraft need to receive a traffic information broadcast from the ground (unless we assume that all aircraft are equipped for automatic dependent surveillance – broadcast) which includes equivalent data on managed aircraft. These broadcasts may be constrained to every 5 or 12 seconds due to the radar update rate.

Dependent surveillance broadcasts need to be received by the ground and integrated into ground automation to provide controllers an equal situation awareness to that of free maneuvering aircraft, with a concurrent CD&R process. The CD&R systems in air and ground are equivalent in capability but are not necessarily built to the same design. The look-ahead horizon (LAH) of the airborne CD&R is at least as far as "A" seconds, with the LAH of the certified safe CD&R algorithms set at "B" seconds. Because the ground must be capable of sending a conflict advisory to the managed aircraft "C" seconds before the conflict, its LAH must be at least "C" seconds. The ground LAH for managed aircraft will be determined by the requirements and capabilities of the CD&R algorithms employed by the ground to provide conflict resolution capabilities to managed aircraft.

Further Details on CE 5 Operations:

ATSP View The principal interfaces between the controller and free maneuvering aircraft are the issuance of traffic management directives, including RTAs, for traffic management purposes; and potential communications within the conflict advisory zone, to be determined by research. The traffic management conditions may exist both in en route cruise and in transition. In developing an RTA, first an Estimated Time of Arrival (ETA) is given by the flight crew. Second, a soft RTA is negotiated between ATSP and flight crew at a time "X" minutes ahead of reaching the fix, where "X" is currently assumed 30 minutes for research purposes. Third, a frozen RTA is set to which the flight crew must commit.

If a free maneuvering aircraft misses an RTA, the re-planning responsibility is shared. The service provider will find a gap for aircraft re-sequencing, provide a new RTA, and the aircraft will replan its trajectory to meet it.

The controller monitors all aircraft, both managed and free maneuvering, in his or her sector. Monitoring conflicts which do not involve managed aircraft is a secondary workload requirement similar to today's Visual Flight Rules (VFR) flight following. ATSP automation will monitor whether free maneuvering aircraft are conforming to their broadcast intent and may notify the controller when there are deviations. The controller may issue conflict advisories and path deviation advisories to free maneuvering aircraft, subject to the workload limits of the controller.

Pilot View The flight crew of a free maneuvering aircraft has responsibility for the following functions: **maintaining situation awareness**, **self-separation assurance**, **flight re-planning**, and **adherence to constraints** issued by the ATSP. The last function has been discussed above and is not further addressed here.

Maintaining Situation Awareness

The free maneuvering aircraft has an interactive navigation display that shows weather and traffic data to a distance which will be determined as the concept further matures. Traffic may need to be viewed at least 30 minutes ahead for conflict detection, and weather much farther out for aid in long-range CD&R. Weather information would be best viewed on a second display with a greatly expanded range.

Airborne weather information is integrated based on ground information and on-board weather systems. Information is required on winds, turbulence, and convective weather. It is expected that gridded 4D weather and wind products are available. These may come from centralized sources, then become individually tailored for the flight deck depending on the pilot's weather service provider.

In order for a given free maneuvering aircraft to have situation awareness of other free maneuvering aircraft, each must broadcast its state and intent, with the intent preferably as a 4D trajectory. The required broadcast radius will be determined through research. Initially, 90 nautical miles is assumed. Research will determine if this is sufficient. A traffic information broadcast from the ground provides completeness by showing state and intent of all managed aircraft and free maneuvering aircraft beyond the air-to-air broadcast radius. Flight deck automation merges this information to display relevant traffic. Current research is exploring the idea of "threat-based filtering" which only shows aircraft that could qualify as some level of threat. Longer-range data (out to 300 nmi.) may be more useful in strategic conflict resolution, to implement an FMS trajectory that is nominally conflict-free for as far out as possible.

Self-Separation Assurance

The discussion of self-separation assurance by free maneuvering aircraft is divided into four highly interrelated topics: trajectories, CD&R, flight rules, and issues concerning intent.

To aid in designing separation assurance capabilities, a number of different trajectories are first defined for the purposes of conflict detection and resolution. There are five trajectories for a subject free maneuvering aircraft. These are:

- State-projection trajectory. This is an extrapolation of current position (3D), speed (3D) and heading.

- Commanded trajectory - the route the aircraft's autoflight system actually flies given autoflight commands and aircraft performance constraints, and assuming no more pilot inputs.
- Planning trajectory – best prediction of what the aircraft shall do given all "known intent". This is generally based on the FMS flight plan.
- Provisional trajectory – alternative routes tested for hazards using the planning trajectory method.
- Inferred intent trajectory – modification to the planning trajectory when the aircraft is not maneuvering consistent with "known intent". The operational requirement or benefit to include inferred intent trajectories is not yet established. Inferred trajectories are not in the research baseline but are being explored.

There are three trajectories for surrounding traffic, called the intruder. These are:

- State-projection trajectory (using target state).
- Intent trajectory – based on intruder trajectory broadcast (e.g., intended Trajectory Change Point (TCP)) if available.
- Inferred intent trajectory – possible trajectories for the intruder when no broadcast intruder intent is available. As above, the operational requirement to include inferred intent trajectories is not yet established.

Each free maneuvering aircraft has a CD&R decision support tool which provides the flight crew a conflict alert with an airspace hazard or intruder traffic well ahead of the conflict. Given trajectory prediction accuracy considerations, it is estimated that reliable alerts could be provided about 30 minutes ahead, to be confirmed by research. One or more resolution trajectories are also provided. The CD&R tool utilizes traffic, winds and area hazards in calculating conflict alerts and conflict-free resolution trajectories. Traffic constraints, RTAs, and airspace hazards are also used to constrain the resolutions. Conflict alerts and resolutions are shown on the flight deck's interactive navigation display, to aid the flight crew's situation awareness.

It is a hypothesis that a free maneuvering aircraft can perform adequate trajectory prediction of an intruder to perform CD&R, without having detailed knowledge of the intruder's performance characteristics. This may become critical in transition airspace when most aircraft are performing climbs and descents, and the speeds and altitude change rates differ greatly among different aircraft types.

The initial estimate, to be confirmed by research, is that to fulfill CD&R requirements, a free maneuvering aircraft should broadcast its intent forward through the next two TCPs.

A free maneuvering aircraft should check its entire en route flight plan for airspace conflicts, but only 30 minutes [3] ahead for conflicts with other aircraft due to expected trajectory prediction uncertainties.

Flight rules provide the means for procedural conflict resolution. They specify for particular conflict situations who has lower priority (i.e., who deviates) and what restrictions exist on maneuvering (i.e., how they deviate).

Simple flight rules that are easily recollected and interpreted are preferred to more complicated rules. The optimal level of complexity is a research question, involving tradeoffs among flexibility of maneuver, predictability of maneuver, separation assurance and the ability to make rules transparent to the flight crew through the alerting system.

If a free maneuvering and a managed aircraft are in conflict, the baseline concept gives the free maneuvering the right of way. The free maneuvering aircraft may not, however, create a near-term conflict by changing intent.

A controller assures separation for managed aircraft in the same way that pilots of free maneuvering aircraft assure separation for themselves. In either case, the responsible party may conduct tactical maneuvers for safety reasons. There will be situations where a free maneuvering aircraft makes tactical moves (thus leaving FMS guidance) for safety, thereby having its intent less defined and uncertain to the controller. There will be situations where a controller directs a managed aircraft to make tactical moves for safety, thereby having its intent uncertain to nearby free maneuvering aircraft. This is true even though the aircraft's motion will be broadcast in both cases and will be received by the other party. There still are questions – will that aircraft continue on its current heading? It's turning – how far will the turn go before it straightens out? Will it turn back, and when?

Robust decision support systems are available both to the controller and to pilots of free maneuvering aircraft to handle situations of uncertain intent. In addition, the controller may issue an advisory (datalink or voice) to the free maneuvering aircraft, but this is subject to workload.

<u>Flight Re-Planning</u>

The free maneuvering aircraft has the following restrictions on the flight re-planning function. The aircraft must be able to satisfy separation constraints, avoid short term traffic and area hazards, operate within aircraft performance limitations, and satisfy user preferences to the extent possible. It must be able to re-plan to meet RTAs imposed by ATC, or communicate its inability to comply with the RTAs and request a revised constraint. It must also broadcast new trajectories resulting from new plans. The aircraft is supposed to adhere accurately to its planned trajectory in the absence of disturbances. There may be a penalty for a flight crew not adhering to its broadcast trajectory. The penalty may be in the form of lower priority relative to those that do

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[3] Values up to 30 minutes are expected to provide benefits. Smaller values may be sufficient for operational feasibility. Research has shown en route feasibility in unconstrained operations with 5 minute look-ahead based on state-data only.

adhere. In other words, if you “go tactical” and no longer broadcast intent, you may be sacrificing priority relative to those that stay strategic.

Re-planning may be strategic or tactical. Strategic re-planning is performed by determining a complete solution to one or more problems or constraints, such as hazards or RTAs, prior to executing the solution. Tactical re-planning is performed by selecting and executing a maneuver to avoid a problem before a complete solution is available, with the understanding that additional maneuvers may be required “on the fly”, as the traffic situation develops. Tactical maneuvering implies incomplete knowledge and/or broadcast of intent.

AOC View The AOC interaction with the flight deck or the ATSP is not a central part of the CE 5 concept. For air carrier aircraft, the AOC transmits company constraints to the flight deck as a factor in flight planning and re-planning. Given enough time, the pilot may consult with the AOC and request advice on flight plan changes. The AOC may communicate with traffic management for collaborative decisions which will satisfy traffic flow constraints. All of this activity may influence the ATSP and flight crew actions, and is part of the larger DAG-TM concept, but is behind the scenes as far as examining and implementing en route free maneuvering is concerned.

Functional Flow Charts

Figure 5 is a top-level functional flow diagram of the DAG-TM CE 5 concept. The figure depicts the high level air and ground functions. These functions are color coded and successive figure zoom in on these functions depicting greater levels of detail. Current and future air traffic systems and services are not shown but rather only the functions that must be performed by the DAG-TM software. The interfaces with the pilot, controller, and AOC dispatcher are also shown (see bold lines and print in the figures) however the specific tasks that are associated with each of the human elements of the system are not presented as part of this document.

For example, Figure 6 illustrates the next level of detail for the Autonomous (free maneuvering) Aircraft functions. Figure 7 provides even greater detail on certain of the autonomous aircraft functions identified in green. A similar depiction is also provided for the ground-based functions (Figures 8 and 9).

Figure 5. Top Level Functional Flows

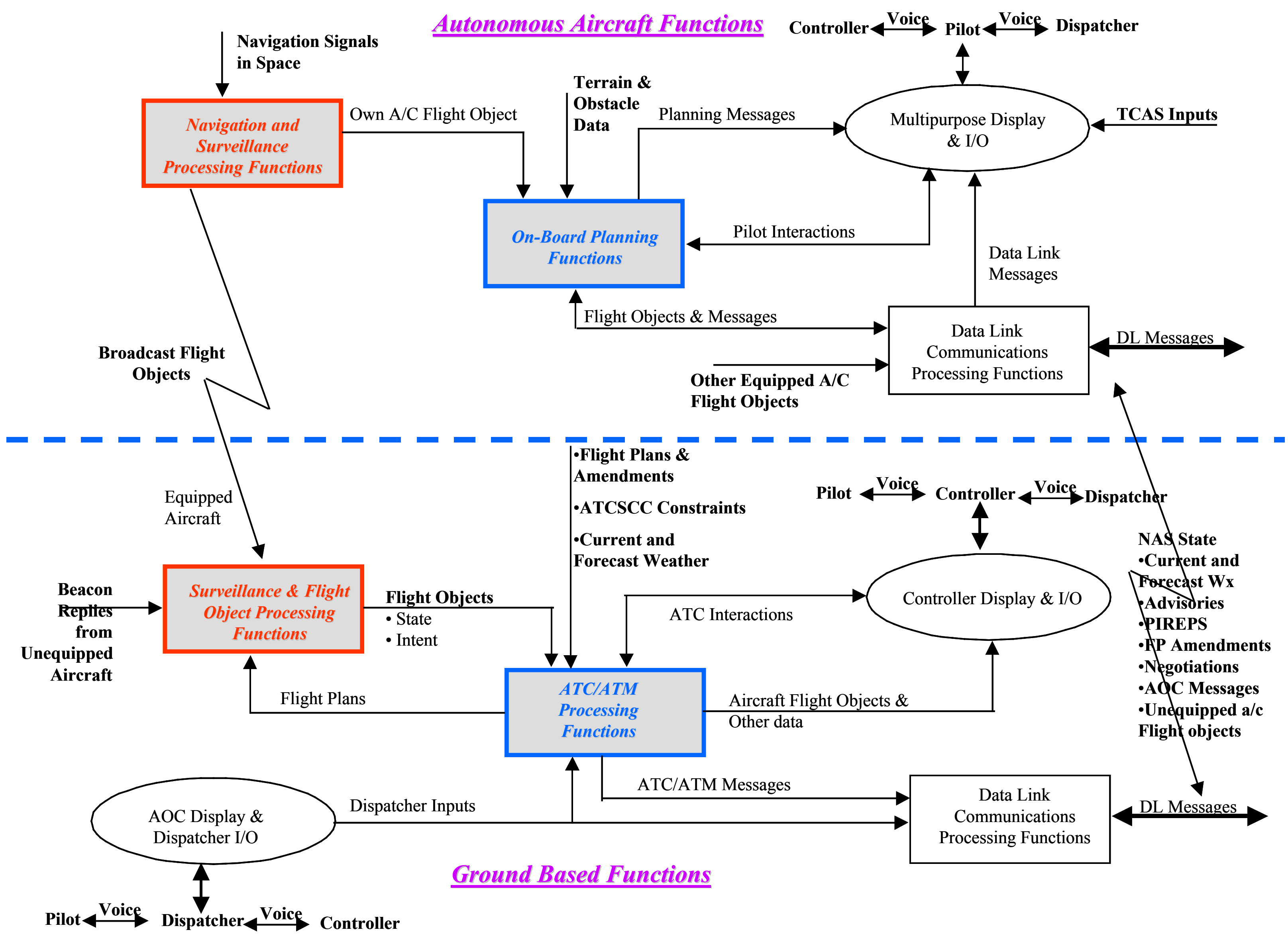


Figure 6. Autonomous Aircraft Functions – Top Level Functional Flows

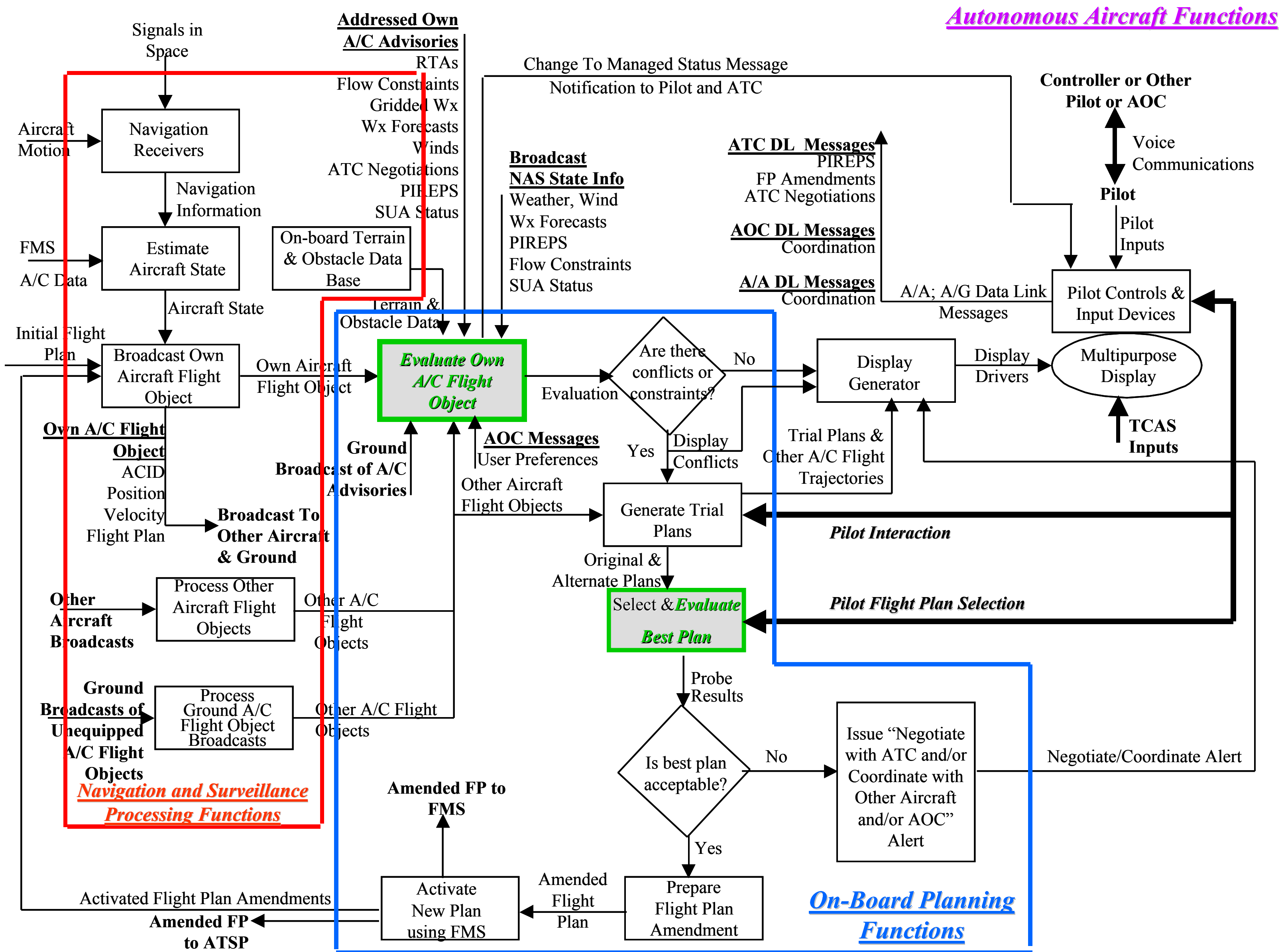


Figure 7. On-Board Planning Functional Flows

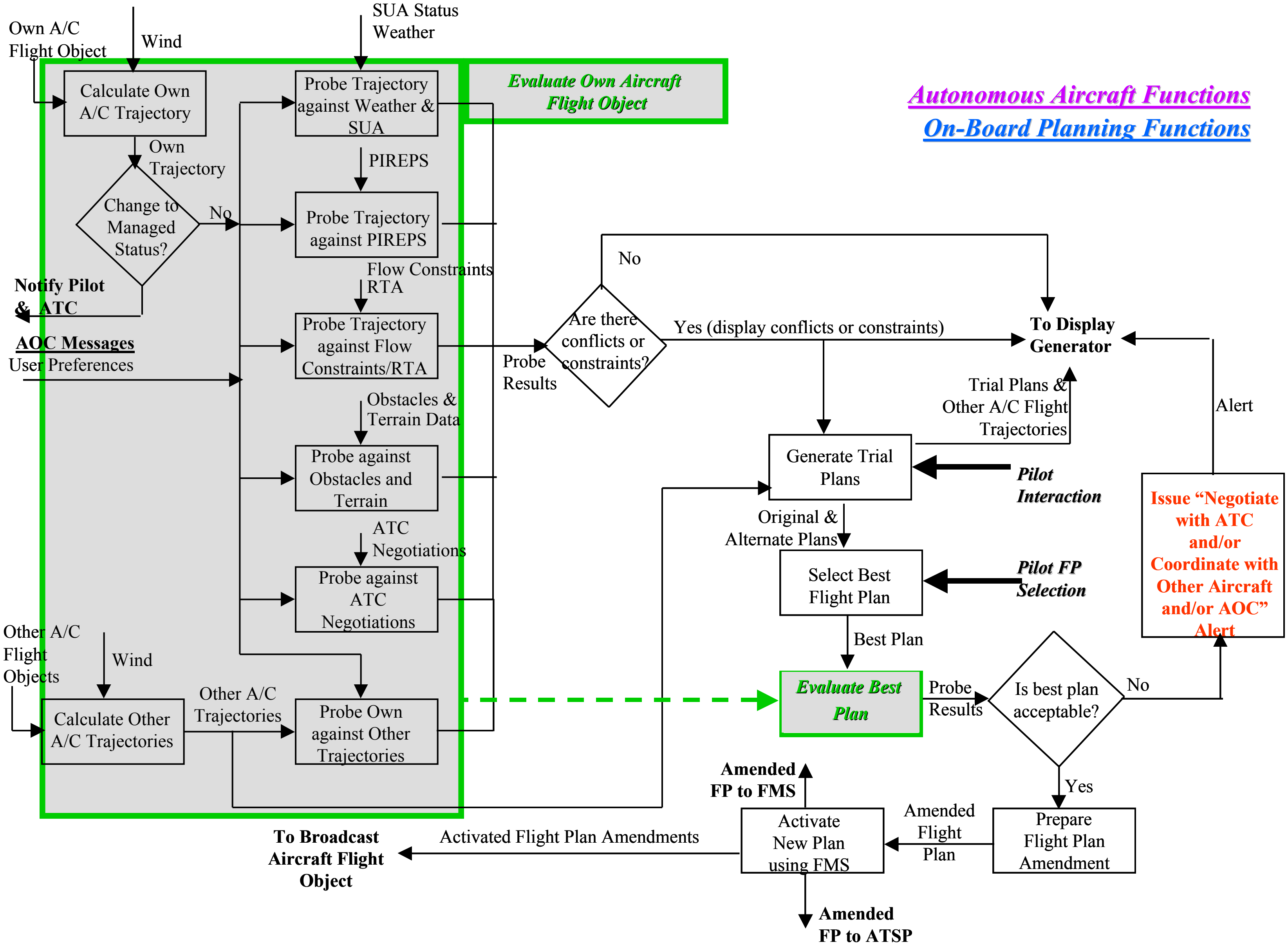


Figure 8. Ground Based Functional Flows

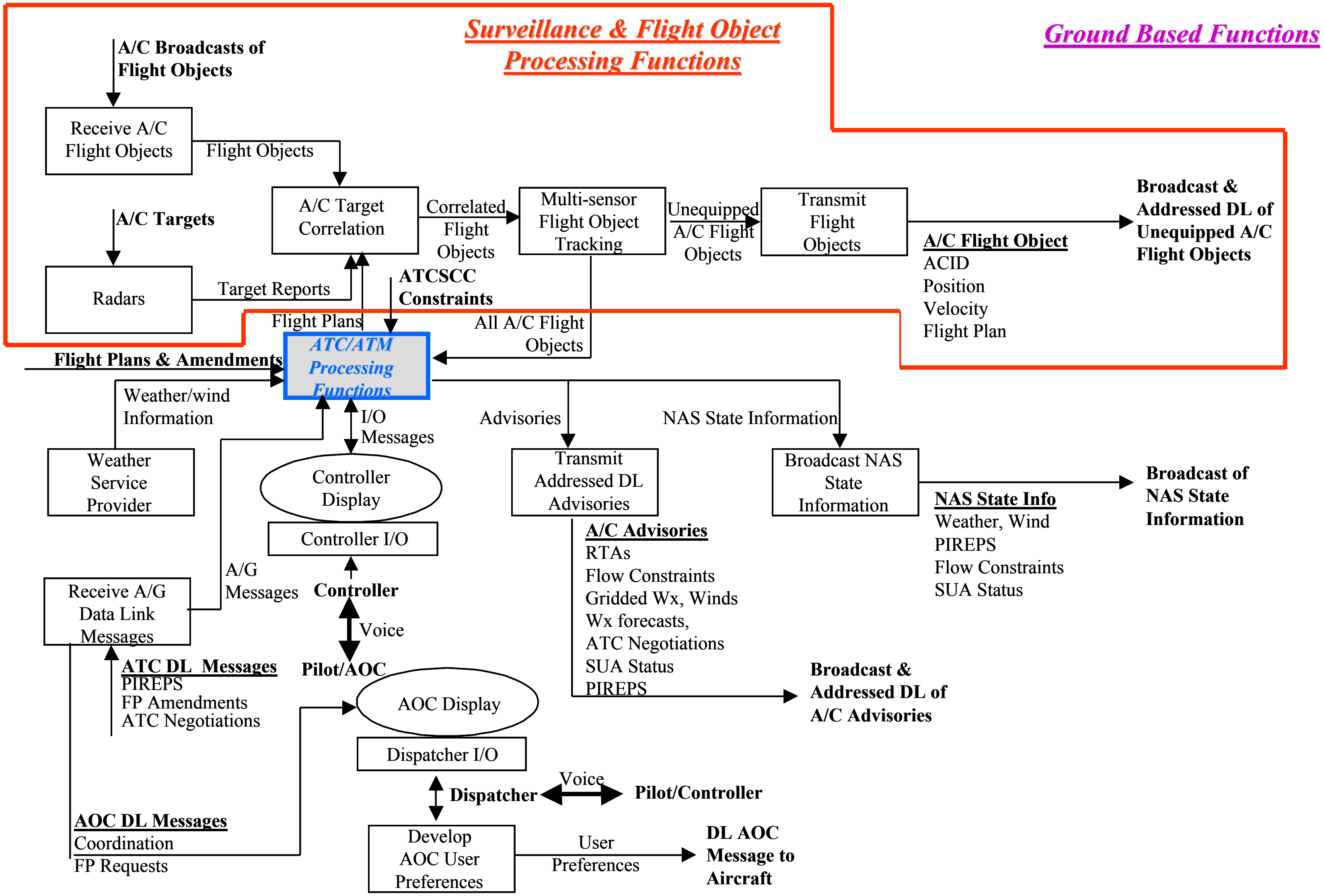
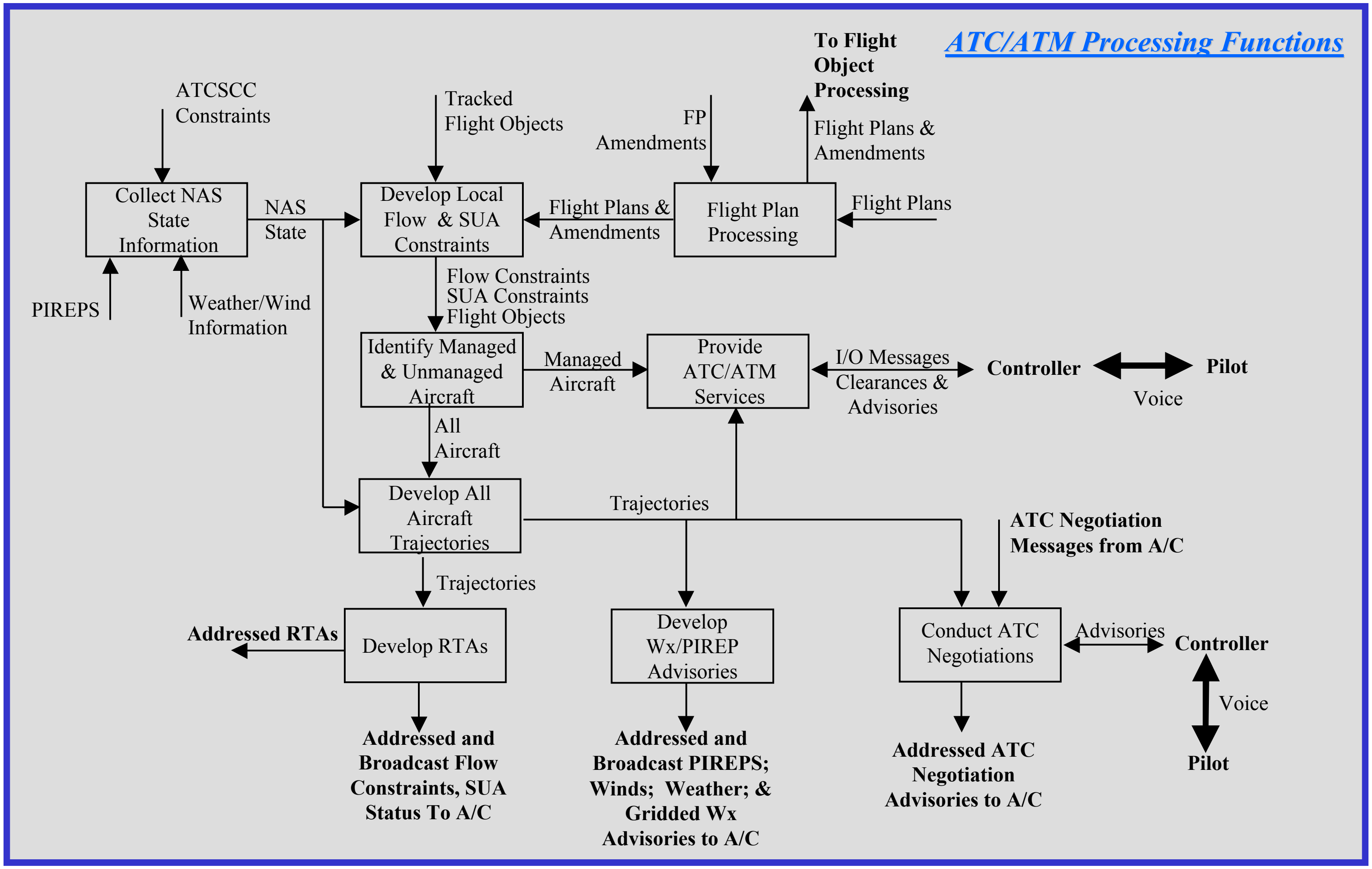


Figure 9. ATC/ATM Processing Functions

Ground Based Functions



5.4 Users/Affected Personnel

In this section the focus is on the roles and responsibilities of each of the active participants in the CE 5 concept. Subsections address the roles and responsibilities of the ATSP, the pilot, and the AOC respectively.

ATSP Roles and Responsibilities: The air traffic controller directs managed aircraft in a similar manner as today, while monitoring the activities of free maneuvering aircraft. The controller continues to send the following four types of messages to aircraft, but only two of these (the last two) apply to free maneuvering aircraft:

- Clearance. This is a required maneuver for maintaining separation (e.g., move to new altitude, new heading). The clearance applies only to managed aircraft.
- ATC instruction. Similar to a clearance but more urgent (e.g. “go around”, “turn left to [new heading]”). Again this applies only to managed aircraft.
- Advisory. Provides a flight crew with awareness of traffic, weather, turbulence, etc. to all aircraft.
- Traffic management directive. Informs flight crew of restricted airspace or RTA assignment. This applies to all free maneuvering aircraft and those managed aircraft capable of meeting an RTA.

Under some circumstances, a free maneuvering aircraft will become managed. This occurs only with controller and flight crew consent. It is a design goal of the concept that this transfer of responsibility authority should be smooth and predictable. The conditions under which such a transfer may occur will be determined by research.

Pilot Roles and Responsibilities: As discussed previously, the free maneuvering aircraft pilot has responsibility for situation awareness, separation assurance, flight re-planning and execution, and adherence to constraints issued by the ATSP.

The pilot has a CD&R system that provides predicted conflict alerts and resolution maneuver options. Resolutions may be strategic or tactical. Strategic resolution is performed by determining a complete solution to one or more conflicts, which may be constrained by RTAs or other factors, prior to executing the solution. Tactical resolution is performed by selecting and executing a maneuver to avoid a conflict before a complete solution is available, or even without ever looking for a complete solution, with the understanding that additional maneuvers may be required.

A free maneuvering aircraft may request information from a controller. Such a request is addressed by the ATSP on a time-available basis similar to the interaction with today’s VFR traffic. In addition, a free maneuvering aircraft may request change of status to managed. This status change must be accepted by the controller before it takes effect.

AOC Roles and Responsibilities: CE 5 does not have significant effects on AOC roles and responsibilities.

Table 4 identifies all potential users or involved personnel, based upon CE 5 operations. It is identical to Table 1. The users involved before and after CE 5 are the same. Their roles and responsibilities change in accordance with the preceding writeups.

Table 4. Users or Involved Personnel in CE 5 Operations

Users or Involved Personnel	CE 5 Operations
Traffic Management Specialist at ATSCSS	
Air Traffic Control Supervisor (ATCS)	
Supervisory Traffic Management Coordinator-in-Charge (STMCIC)	
Operations Supervisors (OS)	
Traffic Management Coordinator (TMC)	
En Route Radar Position – R controller	✓
En Route Radar Associate (RA) – D controller	✓
En Route Radar Coordinator (RC)	
En Route Radar Flight Data (FD) Position	
En Route Non Radar (NR) Position	
Terminal Radar Position – R controller	✓
Terminal Radar Associate (RA) – D controller	✓
Terminal Radar Coordinator (RC)	
Terminal Radar Flight Data (FD) Position	
Terminal Non Radar (NR) Position	
Tower Local Controller (LC)	
Tower Ground Controller (GC)	
Tower Associate	
Tower Coordinator	
Tower Flight Data Position	
Tower Clearance Delivery Position	
Flight Service Station Specialist (FSSS)	
Airline or Aircraft Flight Operations Center (AOC)	✓
Pilot or Flight Crew (FC)	✓

5.5 Support Strategy

To be determined

6. Operational Scenarios

This section discusses and illustrates the modes in which the CE 5 concept has to operate in order to be successful. This discussion is oriented to the full concept. Additional modes may be necessary during transition to the concept.

The section divides the discussion into three sub-sections addressing normal or nominal modes, off-nominal modes, and failure modes.

Normal or Nominal Modes: Normal or nominal modes are conditions that en route free maneuvering is expected to encounter regularly and within which the concept will work in a routine manner. The following is a classification of these modes:

En route non- transition airspace

Figure 10 illustrates en route non-transition modes as a top view. The left-hand panel shows unconstrained airspace that will have a certain number of aircraft-aircraft conflicts. The right-hand panel shows various conditions of constrained airspace (traffic management, excess density, excess complexity, RTA to be flown, weather to be avoided, and SUA activation/deactivation). Note the use of the RTA to manage flow through a constricted corridor[4]. Of course in the CE 5 concept many aircraft will be able to avoid such corridors through adequate flight planning, but others may not be able to because of changing conditions, or will choose to take the corridor because the delay is less than that created by a diversion.

Figure 11 illustrates en route transition modes as a profile view. The left-hand panel shows unconstrained airspace within which climbing, descending and overflying aircraft are operating near a Terminal Radar Control (TRACON) boundary. Many types of aircraft-aircraft conflicts must be protected against, including overflights that conflict with climbing or descending aircraft which are leaving or approaching the TRACON, and aircraft with different performance characteristics descending toward the same fix. The right-hand panel shows constrained operations with similar kinds of constraints as discussed previously. In transition airspace, the RTA is an instrument for efficient merging and sequencing in preparation for the approach and landing procedures within the TRACON. Aircraft in the transition zone, as contrasted with operations outside transition, have to react to constraining situations more quickly and possibly replan more frequently.

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[4] Some scenarios are being studied that have very narrow corridors, and metering is not being used to determine if this solution is needed for such problems. Nevertheless, CE5 can still accommodate it. It means there is a need for en route RTA meeting capability, and probably multiple-RTA-meeting capability on the flight deck.

Figure10. En Route Operational Modes in Non-Transitional Airspace (Top View)

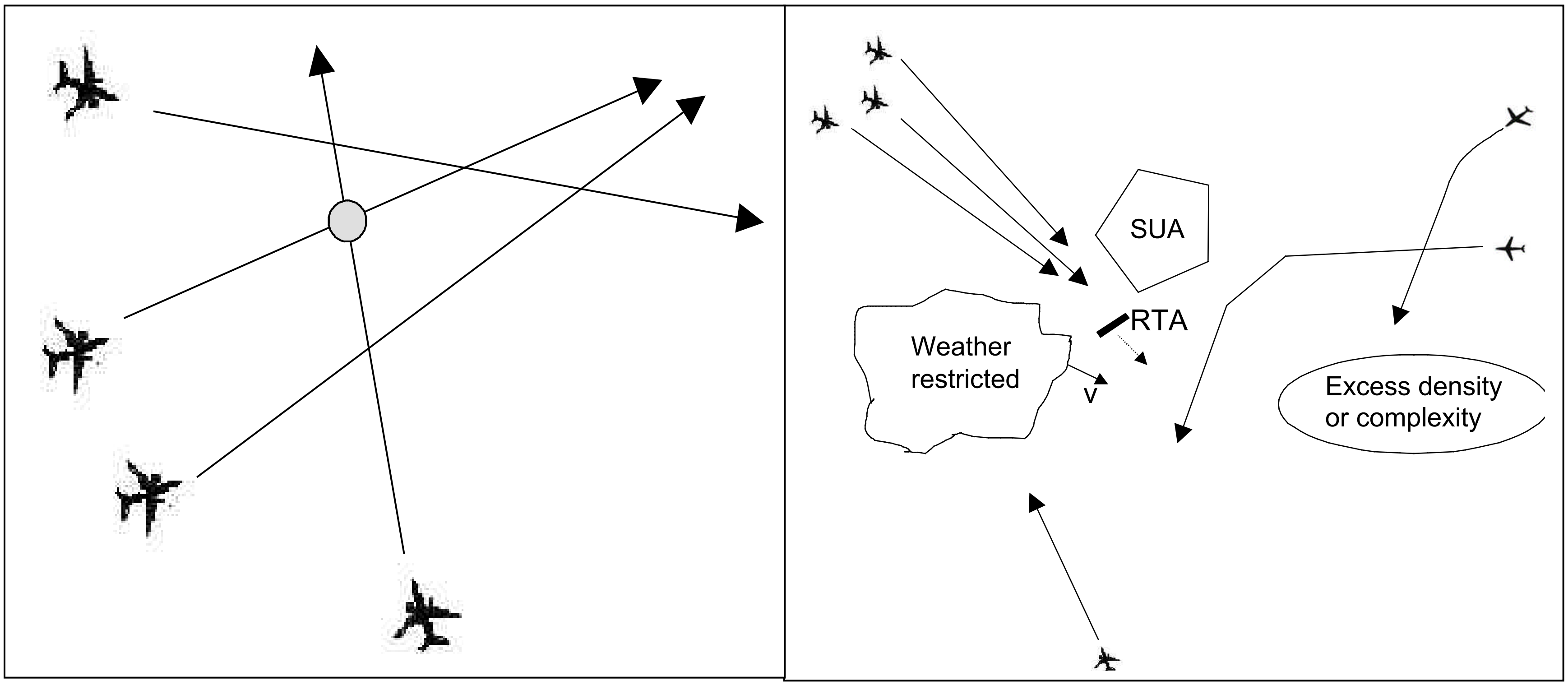
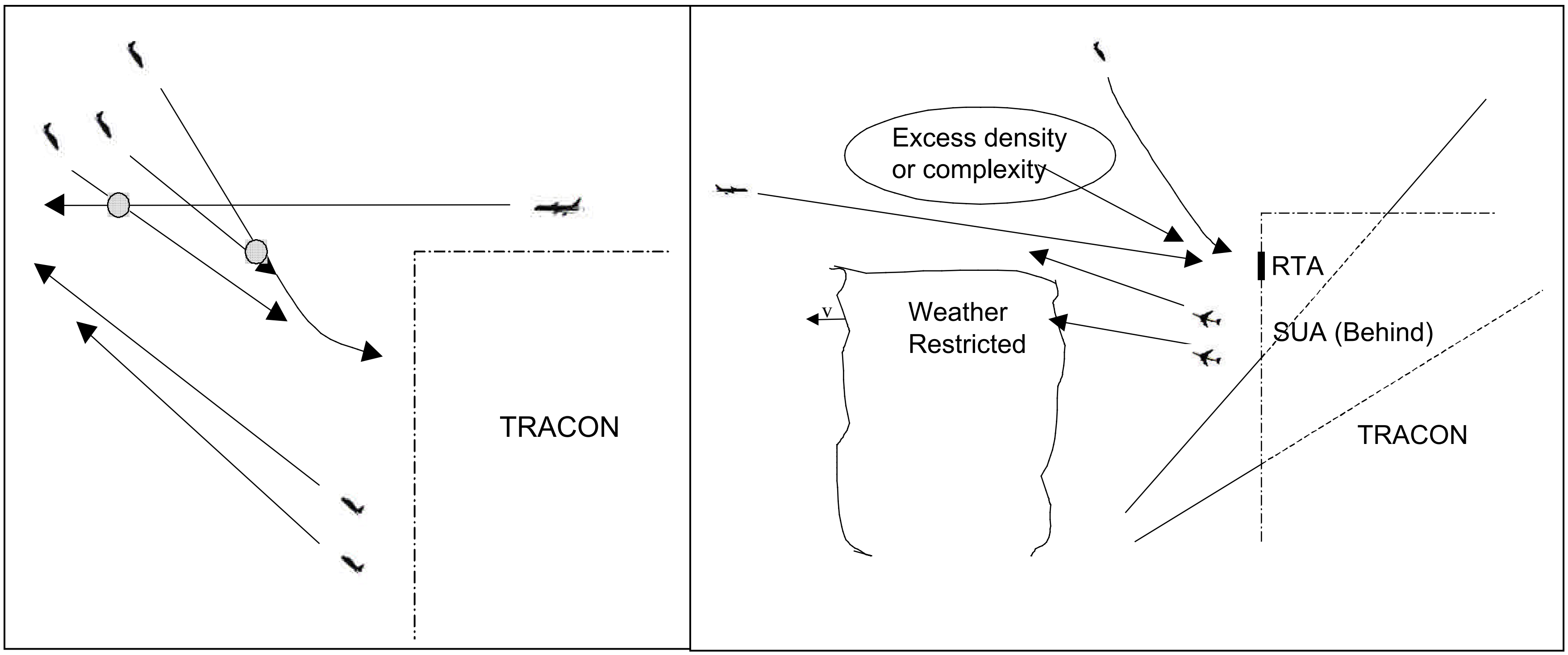


Figure 11. En Route Operational Modes In Transitional Airspace (Profile View)



Rare Nominal Modes: Rare nominal modes are defined as operation in conditions that stress the applicability of the concept. In general these are conditions in which anything changes quickly and/or unexpectedly. Examples are the following:

- Weather
- Large fronts which developed unexpectedly
- Fast moving fronts
- SUA unscheduled activation on short notice
- Traffic complexity developing quickly and not anticipated by traffic management
- An unusual increase in traffic volume

Failure Modes: Failure modes are modes which can apply to each of the nominal or rare nominal modes defined above. A failure mode is a condition which results in the aircraft/ATC system becoming degraded. Performance may be locally substandard during a failure mode, and success is defined as the ability to move to a safe condition.

The following is a classification of failure modes and a description of failures that may occur within each class.

Airborne automation failures (free maneuvering aircraft)

- Lacks intent or performance information
- Sends wrong intent information
- Conflict detection failures (false conflict alert; missed conflict alert)
- Conflict resolution fails to safely resolve conflict
- Avionics failures (display, autopilot, flight control system)

Ground automation failures

- Conflict detection failures (false conflict alert; missed conflict alert)
- Conflict resolution fails to safely resolve conflict
- Ground DST failures (displays, computer)
- Flight advisories failure (no weather advisories; no airspace advisories)

CNS infrastructure failures or degradation

- Traffic information failure (e.g., TIS-B)
- Addressed ground-air/air-ground datalink failure
- Lost communication with autonomous aircraft
- Lost communication with managed aircraft
- Radar failure
- GPS system failure

Dependent surveillance failures (receiver, transmitter, datalink)

Pilot errors (free maneuvering aircraft)

- Error in setting autopilot so that aircraft flies off pilot's intended course
- Pilot changes flight plan without filing change
- Pilot flies off broadcast planning trajectory
- Pilot maneuvers to create conflict
- Pilot fails to resolve detected conflict
- Failure to follow flight rules

ATSP errors

- Controller vectors managed aircraft to cause conflict with free maneuvering aircraft
- Controller fails to transmit TM directives to free maneuvering aircraft for airspace avoidance, weather front, saturated sector, or revised RTA
- Air/ground integration failures such as conflicting constraints, failure of flight rules, assigned "frozen" sequence and RTA are overcome by dynamic events

7. Summary of Impacts

7.1 Operational Impacts

The major operational impact resulting from DAG-TM CE 5 is the changed roles for the ATSP and flight crew, both in terms of separation assurance and constraint conformance. These have been described above. In addition, there are changes in the NAS infrastructure that are required in order to implement CE 5. These are described in the areas of Communications, Navigation, Surveillance, Automation, Weather, and Traffic Management.

Communications: CE 5 relies on DAG-TM CE 0, Information Access/Exchange for Enhanced Decision Support, to define required communications. Ground-to-air communications with free maneuvering aircraft are both by datalink and voice. Datalink communications are both broadcast and addressed. The ATSP broadcasts advisories on SUAs, congested areas, flow constraints and weather, and provides detailed traffic information to be utilized by the flight deck's decision support tools. Aircraft-specific advisories and flow constraints such as RTAs are sent by addressed datalink. Voice communication may be used for this latter function but on an exception basis.

Weather service providers send winds and weather information, probably as gridded products, via addressed datalink. These products are tailored to the aircraft position and user planning requirements.

Air-to-ground communications from free maneuvering aircraft are by addressed datalink and voice. Addressed messages include negotiations concerning flow constraints, message received, and accept/reject action. Voice communication may be used for these purposes but by exception.

Air-to-air addressed datalink communications between free maneuvering aircraft may occur during aircraft-aircraft conflicts in the cooperative resolution zone. In addition, free maneuvering aircraft issue surveillance broadcasts, discussed below.

There is no change in managed aircraft communications except that if the managed aircraft has datalink, controllers may send directives via addressed datalink. The air-ground messages would include message received and accept/reject.

Navigation: There are no new functional navigation requirements imposed on the service provider by the CE 5 concept. GPS (or area navigation (RNAV) system meeting the RNP requirement) is assumed certified as a sole means of navigation and is relied on as part of the aircraft's state information and to check its trajectory adherence accuracy.

The free maneuvering aircraft must have an advanced FMS capable of adhering to a planned 4D (i.e., position, altitude, and time) trajectory to some defined level of accuracy, to be determined by research.

Surveillance: Free maneuvering aircraft must broadcast information for surveillance purposes based on the aircraft's trajectory data calculated by its FMS. It broadcasts state and intent data, with state data at 1 second intervals and intent data every nth broadcast, where the value of n is a research question. How much information is required in the intent messages, namely level of detail and time period, will be determined by research. The initial assumption is two trajectory change points, or enough TCPs to cover 30 minutes of flight, whichever is greater.

The service provider must receive these broadcasts from free maneuvering aircraft and perform data fusion with radar surveillance information and flight plan data. This process creates a comprehensive picture of traffic state and intent including both free maneuvering and managed aircraft. This traffic information is broadcast for reception by free maneuvering aircraft to provide them with traffic situation awareness that extends beyond airborne surveillance broadcast datalink range.

Automation: Free maneuvering aircraft must have the following automation capabilities:

- Collect and process intruder aircraft data
- Collect and process area hazard data
- Develop knowledge of state and intent of itself and intruder traffic
- Perform CD&R, meeting multiple simultaneous airspace and traffic management constraints
- Perform trajectory re-planning
- Accept user preferences
- Provide interactive navigation display for flight crew situation awareness and alerting
- Prioritize constraints, including managing over-determined situations, namely where there is no conflict resolution which satisfies all constraints

The service provider needs to develop an increased surveillance data fusion capability as described above for the purpose of providing the controller with a good decision support capability. Specific requirements for controller decision support and displays for the CE 5 concept need to be further developed.

Weather: Improved wind and weather models and information distribution are needed for free maneuvering aircraft to accurately plan and fly their trajectories. Accurate winds are needed for proper functioning of the CD&R routines.

The same scope and detail of weather information is available to the ATSP as to the free maneuvering flight crews. It is important that the data set be common to all users and the ATSP, so that during implicit coordination the different actors will perform as expected.

Traffic Management: There are no changes required for national traffic management, that is at the Air Traffic Control Systems Command Center level. The CE 5 concept can utilize traffic management directives in whatever form they may take. However, improvement in collaboration between the TMC and the flight crew, and use of the 4D flight object, would enable real-time user preferences to be incorporated into traffic management constraints.

7.2 Organizational Impacts

To be determined

7.3 Impacts during Development

DAG-TM CE 5 is at a very early stage of development. As such, it is difficult to determine the impacts on the user, acquirer, and maintenance organizations during development. It is however required that FAA air traffic controllers participate in the development process during demonstration and test phases. Significant impacts are expected on the user, developer, and on the ATM system personnel during development because of the major ATC paradigm shift that will be caused by CE 5.

8. Analysis of the Proposed System

8.1 Summary of Advantages

The benefit mechanism along with other potential benefits are discussed here in the context of the metrics associated with AATT goals. The following top-level metrics have been defined and are discussed in the subsections below.

- Capacity
- Flexibility
- Efficiency
- Predictability
- Safety
- Access
- Environment
- Scalability
- Global Interoperability

<u>Capacity:</u> The following capacity-related potential benefits have been identified.

- An increased volume of airspace can be utilized by free maneuvering aircraft not following a fixed route structure. This is accomplished by many of these aircraft fanning out on routes parallel to heavily used routes, which they will choose to do to avoid congestion.
- Since free maneuvering aircraft have increased situation awareness, excess separation buffers used by controllers today can be removed for these aircraft, increasing operational densities in some situations.
- Close trajectory management by free maneuvering aircraft flight crews allows increased RTA conformance, which leads to increased transition airspace throughput.

<u>Scalability:</u> The following scalability-related potential benefits have been identified. Scalability refers to the capability of the air traffic system to continue to operate successfully with continually increasing traffic volumes. In today's system, controller workload is a strong function of traffic volume since every aircraft is managed. Under free maneuvering, free maneuvering aircraft do not need to be managed by the ATSP and therefore controller workload is a much weaker function of traffic volume. Thus traffic volume could be permitted to increase with the same level of controller resources.

Scalability has two aspects, operational and economic.

- Each additional free maneuvering aircraft contributes its own surveillance infrastructure and provides its own separation assurance. This system accommodates growth better than a centralized system that may have limits in capacity to handle traffic growth. Whereas the current paradigm of centralized human planner/controller does not scale with large traffic growth, a distributed system consisting of free maneuvering aircraft growing with the traffic along with ground controllers, is readily scalable.

- Capital and recurring costs of infrastructure and operations for a single service provider are reduced.

Flexibility: The following flexibility-related potential benefits have been identified.

- User preferences for free maneuvering aircraft are implemented directly by the user without ATSP approval.
- The ability to free maneuver increases the flight crew's ability to follow user preferences, and their range of solution options to traffic problems.
- The lack of route structure and ability to use the entire airspace allows increased flight plan options for free maneuvering aircraft.
- Operators of fleets of free maneuvering aircraft have greater business flexibility in managing their fleets.

Efficiency: The following efficiency-related potential benefits have been identified. These are separated into benefits to users and to the service provider.

Users

- Free maneuvering users should experience reduced operating costs (time and fuel) and reduced delays, due to:
  - Increased predictability of operations
  - Capability for optimized routing
  - Reduced excess spacing buffers
  - Reduced excessive resolution maneuvers
- There will be reduced voice communications for free maneuvering users.
- As the percentage of free maneuvering aircraft increases, managed aircraft should experience reduced delays, since they are a subset of the total traffic and the free maneuvering aircraft are effectively increasing capacity.

ATSP

- The service provider has CD&R and related decision support for ATC clearance advisories.
- The service provider has reduced voice communications since there is little voice contact with free maneuvering aircraft.
- Because many aircraft will have self-separation capability under free maneuvering, the ATSP can focus more on aircraft that do not have self-separation capability. Therefore, the curve of workload as a function of traffic density will be below that experienced by today's ATC system.
- ATSP can focus on traffic management and less on traffic control.

Predictability: The following predictability-related potential benefits have been identified.

- Free maneuvering aircraft are broadcasting their intent. When intent changes, the new intent is broadcast, and maintains predictability of that aircraft for other aircraft and the ATSP.
- A trajectory orientation enables free maneuvering aircraft flight crews to improve trajectory predictability.
- Increased trajectory adherence increases the predictability of RTA conformance, which in turn increases the predictability of arrival traffic.

Safety: The following safety-related potential benefit has been identified. This class is limited to direct safety benefits which have not been implied in the other benefit areas.

Both free maneuvering aircraft and the ATSP have situation awareness concerning potential conflicts. This redundancy reduces the probability of separation assurance failure.

Access: The following access-related potential benefits have been identified. Access refers to the ability of users to obtain access to airport, airspace, and ATC services.

- Integrated mixed-equipage operations maintains access to all airspace as contrasted with segregated airspace concepts (e.g., European).
- En route free maneuvering enables more frequent use of off-route regions.

Environment: More efficient trajectories means less fuel is burned per flight, providing improved environmental benefits.

Global Interoperability: The following potential benefits relating to global interoperability have been identified.

- Assuming harmonized ATC systems in the world, free maneuvering aircraft have reduced equipage and training costs for international operations.
- Free maneuvering aircraft have some capability for situation awareness and trajectory re-planning throughout the world, even if no harmonization exists or ground facilities are lacking.

8.2 Summary of Disadvantages/Limitations

If DAG-TM CE 5 operations fulfill the objectives set for the concept, there are few, if any disadvantages or limitations inherent in the concept. This does not mean that it has been proven that the benefits achievable with CE 5 exceed the implementation costs (e.g., research, development, equipage). This question, and other research issues are identified in the DAG-TM Research Plan (Reference 6) and will be investigated during DAG-TM research.

8.3 Alternatives and Tradeoffs Considered

DAG-TM CE 5 is at a very early stage of development. As such, several alternatives and tradeoffs yet to be identified will be investigated as part of the concept research effort.

9. Notes

Acronyms

4D	4 Dimensional
AATT	Advanced Air Traffic Technologies
A/C	Aircraft
ADS-B	Automatic Dependent Surveillance – Broadcast
AOC	Airline Operations Center
AOP	Airborne Operations Planner
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCS	Air Traffic Control Supervisor
ATCSCC	Air Traffic Control Systems Command Center
ATM	Air Traffic Management
ATSP	Air Traffic Service Provider
CD&R	Conflict Detection and Resolution
CE	Concept Element
CNS	Communications, Navigation, and Surveillance
CPDLC	Controller Pilot Data Link Communications
DAG	Distributed Air Ground
DL	Datalink
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FC	Flight Crew
FD	Flight Data
FP	Flight Plan
FMS	Flight Management System
FSSS	Flight Service Station Specialist
GC	Ground Controller
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronic Engineers
I/O	Input/Output
LAH	Look Ahead Horizon
LC	Local Controller
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NR	Non Radar
NRA	NASA Research Announcement
OCD	Operational Concept Description
OS	Operations Supervisor
PIREP	Pilot Report
RA	Radar Associate
RC	Radar Coordinator
RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival

RTCA	RTCA, Inc.
SSR	Secondary Surveillance Radar
STA	Scheduled Time of Arrival
STMCIC	Supervisory Traffic Management Coordinator In Charge
SUA	Special Use Airspace
TCAS	Threat Alert and Collision Avoidance System
TCP	Trajectory Change Point
TFM	Traffic Flow Management
TIS-B	Traffic Information Service - Broadcast
TM	Traffic Management
TMC	Traffic Management Coordinator
TRACON	Terminal Radar Control (facility)
VFR	Visual Flight Rules
WX	Weather